

Lawrence Livermore National Laboratory

Advanced Energy Pathways Project: Results from System Modeling



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**California Climate Change Conference
2008**

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Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

LLNL-PRES-406840

Introduction and credits

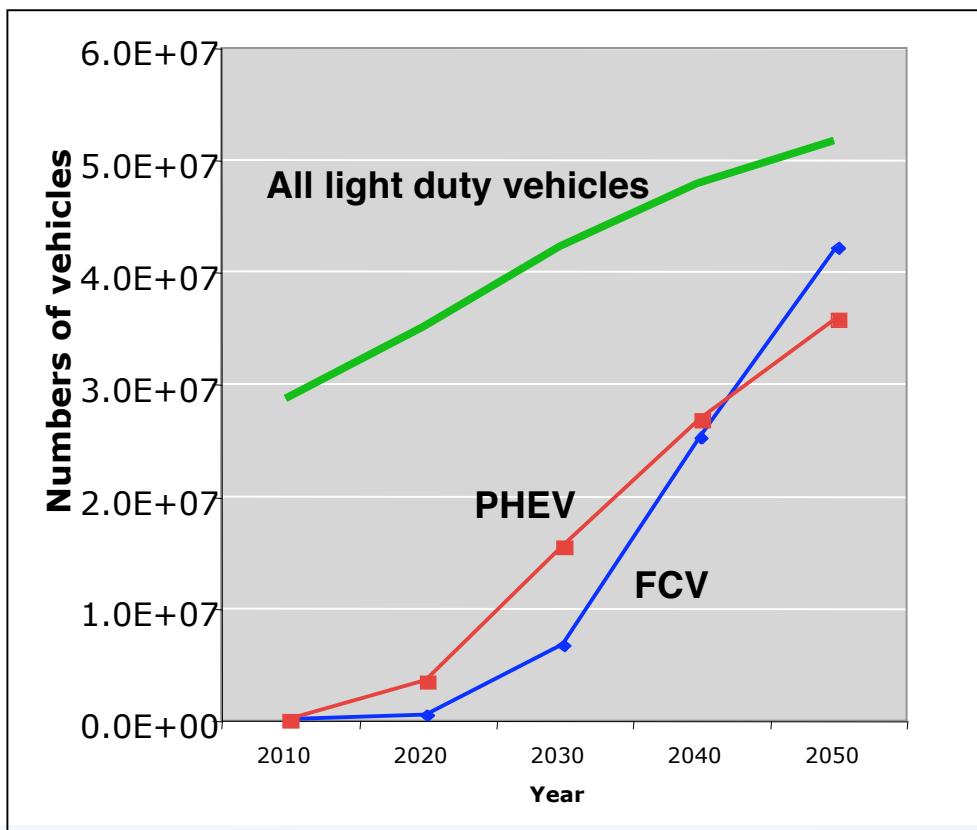
- The Advanced Energy Pathways Project assessed:
 - the technologies needed to provide energy for advanced vehicles
 - impacts on the balance of the system: electric generation capacities, emissions, costs
- Team
 - Modeling done by LLNL
 - Alan Lamont, Rich White, Jeff Stewart
 - Major technical inputs for hydrogen and transportation from UC Davis
 - Chris Yang, Ryan McCarthy, Joan Ogden
 - Sponsored at CEC by Guido Franco, assisted by Suzanne Phinney

Objectives of the model

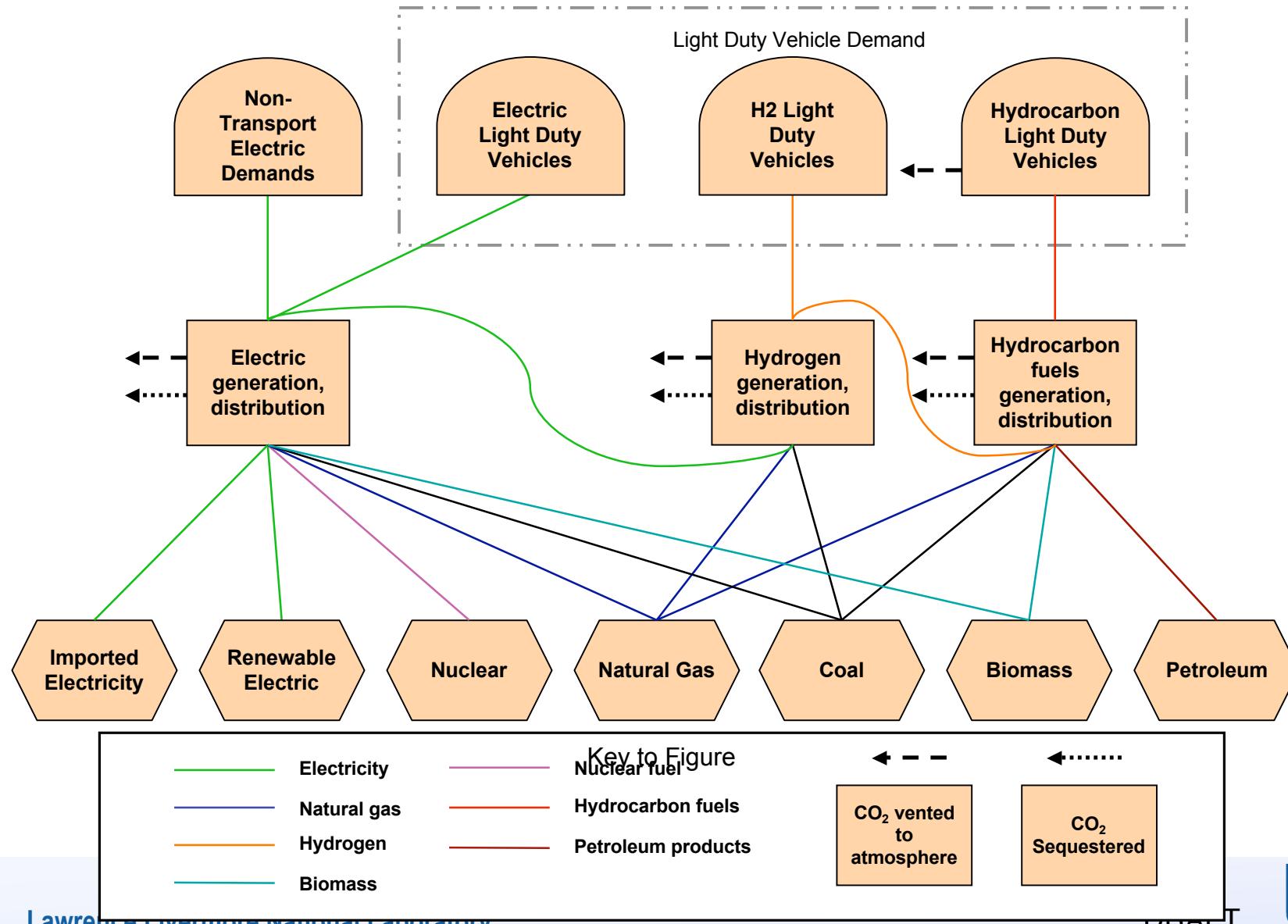
- Assess the changes caused by penetration of advanced vehicles
 - Note: not assessing the competition between vehicles
 - System capacities and production
 - System costs
 - Time patterns of PHEV charging and H₂ production
 - CO₂ emissions (quantities and sources)
 - H₂ production pathways
 - Resource demands
 - Impact of RPS--interactions with advanced vehicles

Six basic scenarios modeled

- 3 vehicle scenarios: All conventional, FCV, PHEV
 - Vehicles assumed to penetrate on a fixed trajectory
- Two policy scenarios: no RPS, and 20% RPS
- Each vehicle scenario run with, and without RPS



The model includes electric and vehicle fuels sectors



Features of the model

- Cost minimizing
- Hour-by-hour
 - Correctly uses intermittents and their coincidence with demand patterns
 - Models patterns of fueling
- Storage
 - Time patterns of on-board charging of PHEVs and system storage in H₂ production and distribution
- Hydro Dispatched optimally for power generation

What is given exogenously, and what is solved inside the model

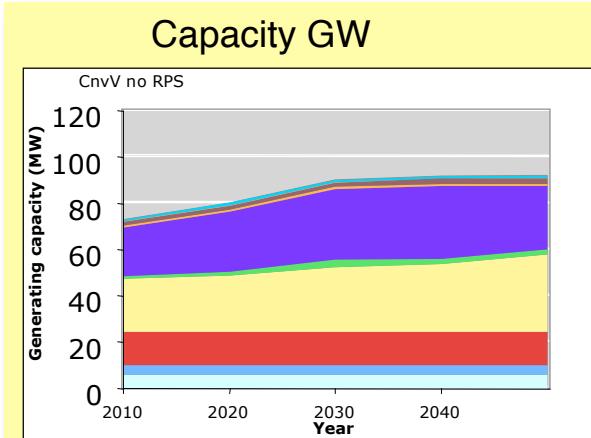
Boundary conditions that are given	Variables determined within the model
<ul style="list-style-type: none">▪ Vehicle penetration rates --> no economic competition between vehicles▪ Annual vehicle fuel and direct PHEV electricity demands▪ Fueling patterns for FCV▪ Natural gas and crude oil prices▪ Total hydro capacity and energy available▪ Capacities of each type of renewable generator, for the RPS cases▪ Nuclear and imported power	<ul style="list-style-type: none">▪ Capacities and dispatch in electric sector▪ Indirect demands for electricity from transportation sector▪ H2 production/distribution pathways (capacities and quantities)▪ H2 production and on-site storage patterns▪ PHEV charging, and on-board storage patterns▪ Hydro dispatch

Outline of results

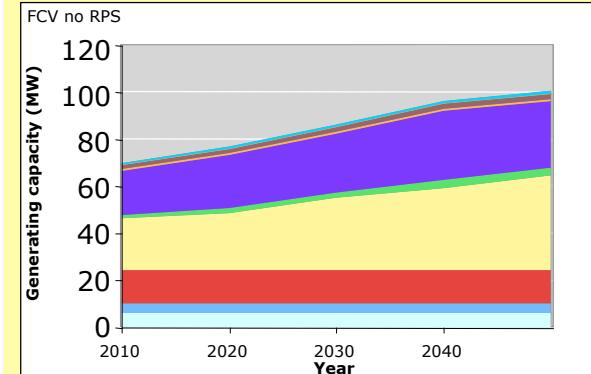
- Changes in capacities and generation under the vehicle scenarios
- Operation of the system
 - Electric dispatch patterns
 - H₂ production patterns
 - PHEV charging patterns
- System wide variables (costs, emissions) and their components
- Impact of the RPS

FCV and the PHEV change the electric system capacities and generation

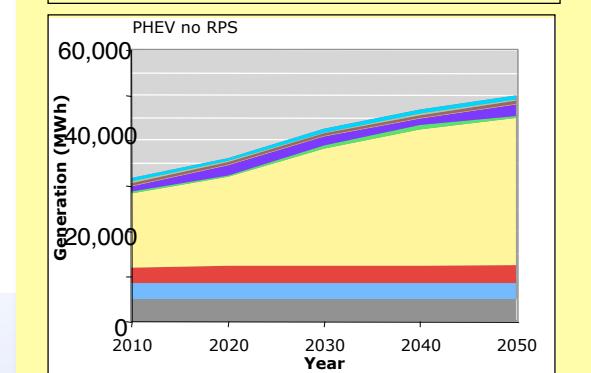
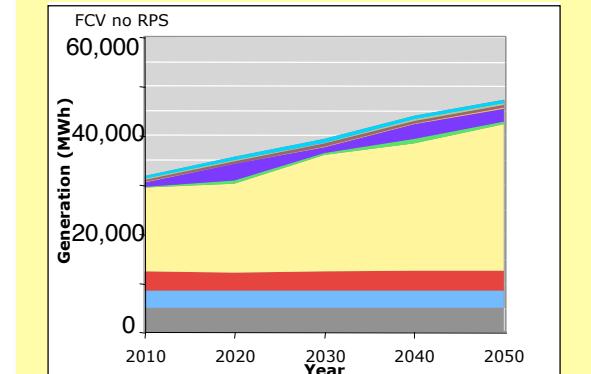
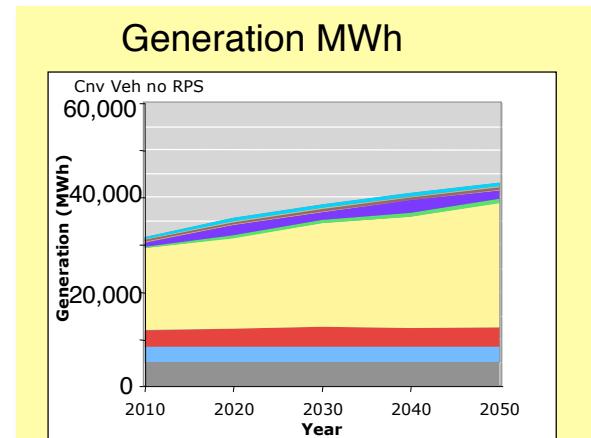
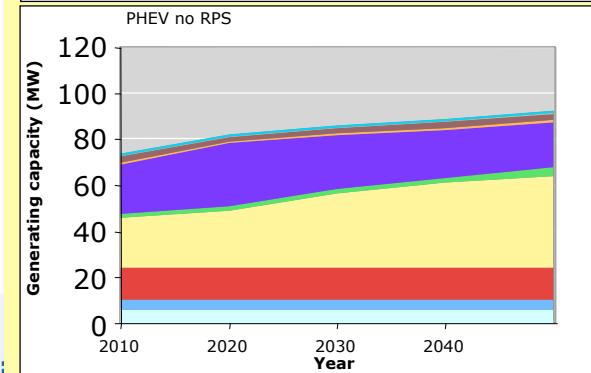
Conventional vehicles



Fuel Cell vehicles

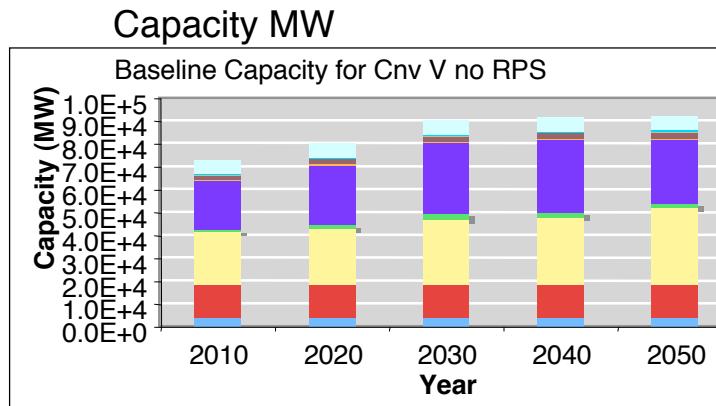


Plug-in Hybrid vehicles

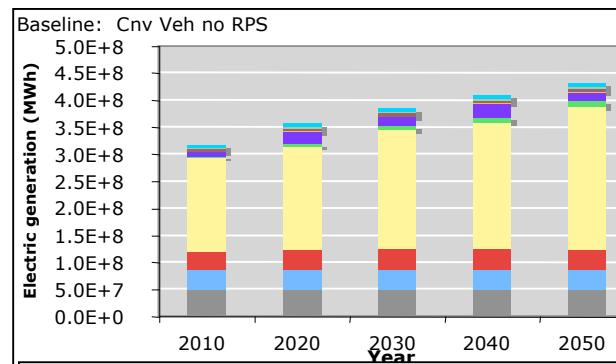


Advanced vehicles increase combined cycle capacity and generation

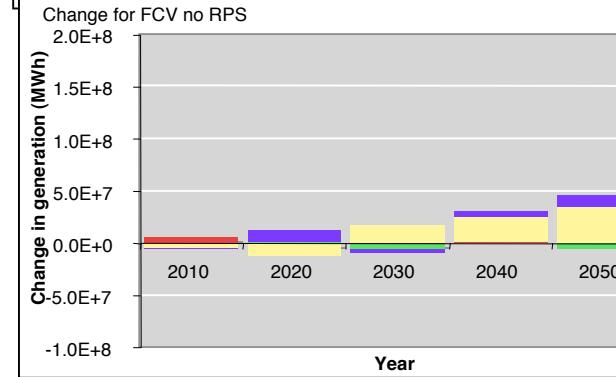
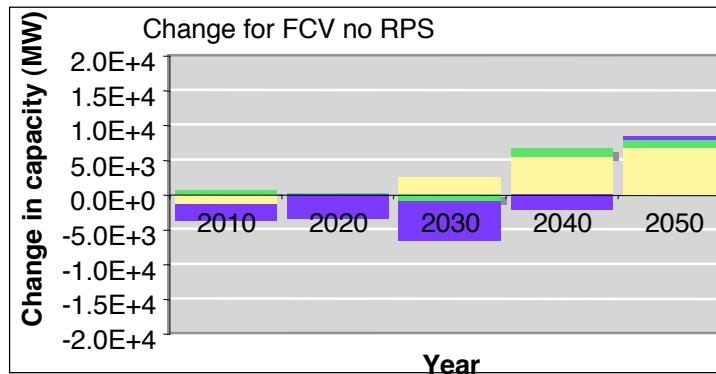
Conv V



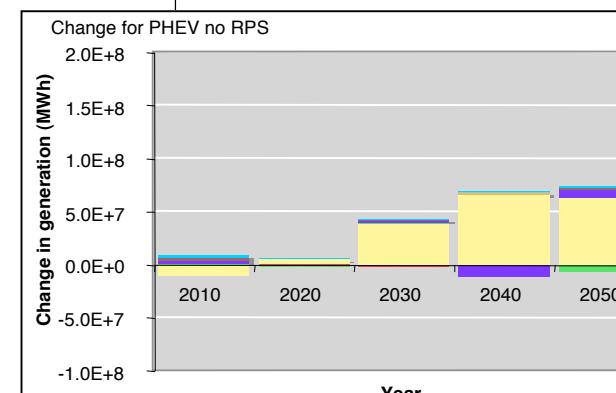
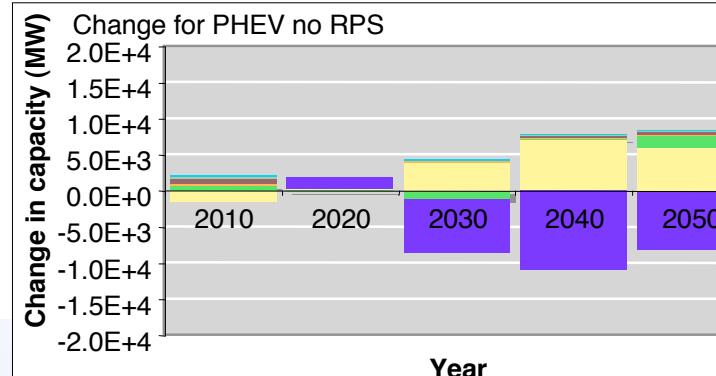
Generation MWh



FCV



PHEV

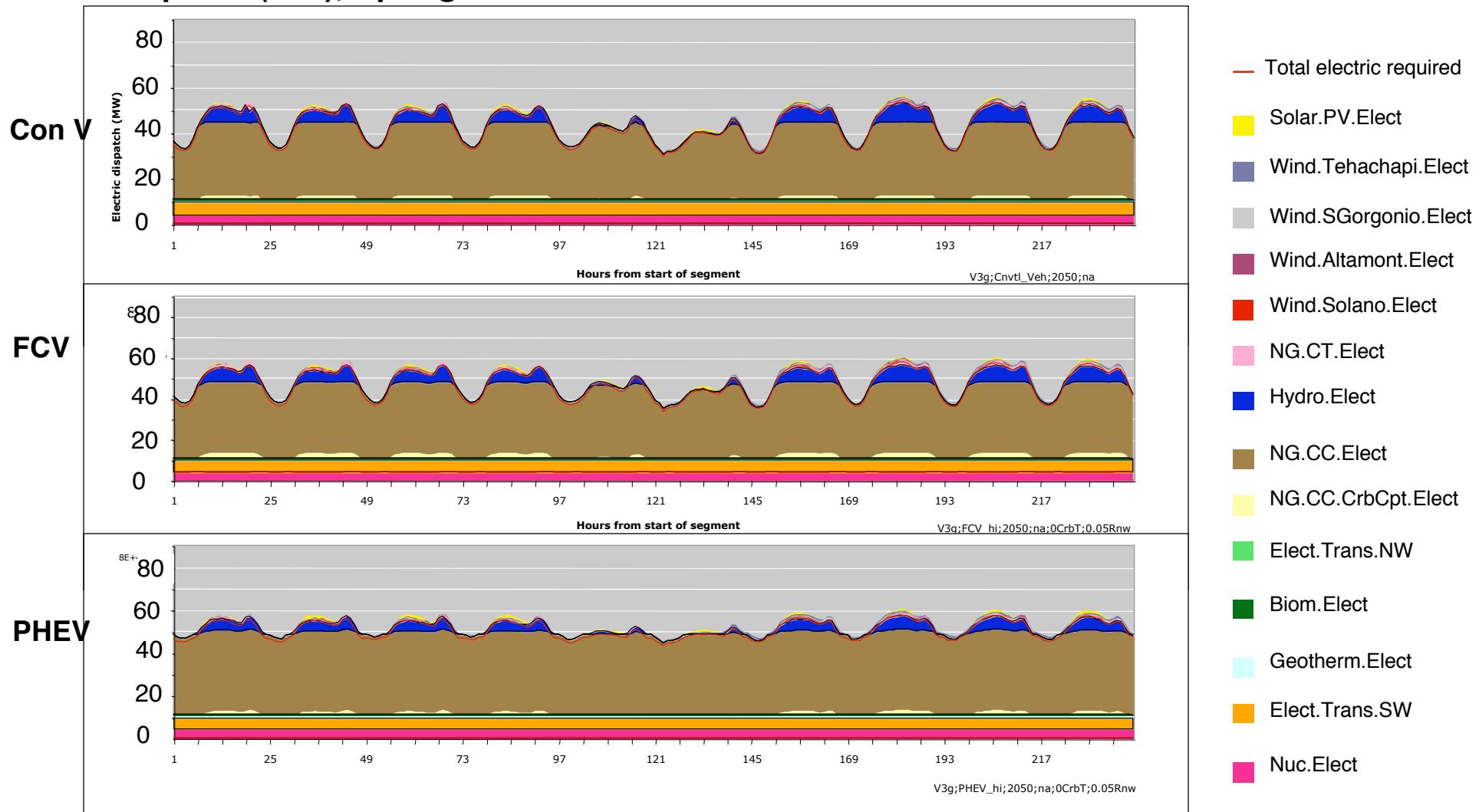


Operation of system under PHEVs and FCV

- Electric dispatch (conventional vehicles, FCV, PHEV)
- PHEV charging patterns (changes spring to summer, indicates need for smart grid)
- H2 production patterns (affected by electric prices in the summer)

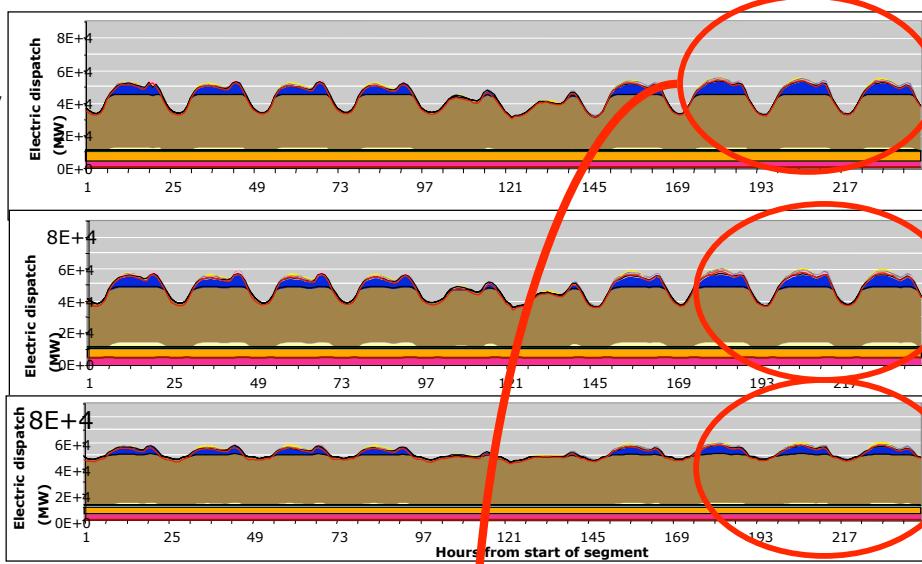
Advanced vehicles increase the overnight minima and increase generation capacities

Dispatch (GW), Spring 2050



A more detailed look at the impacts on capacity

Conv V



FCV

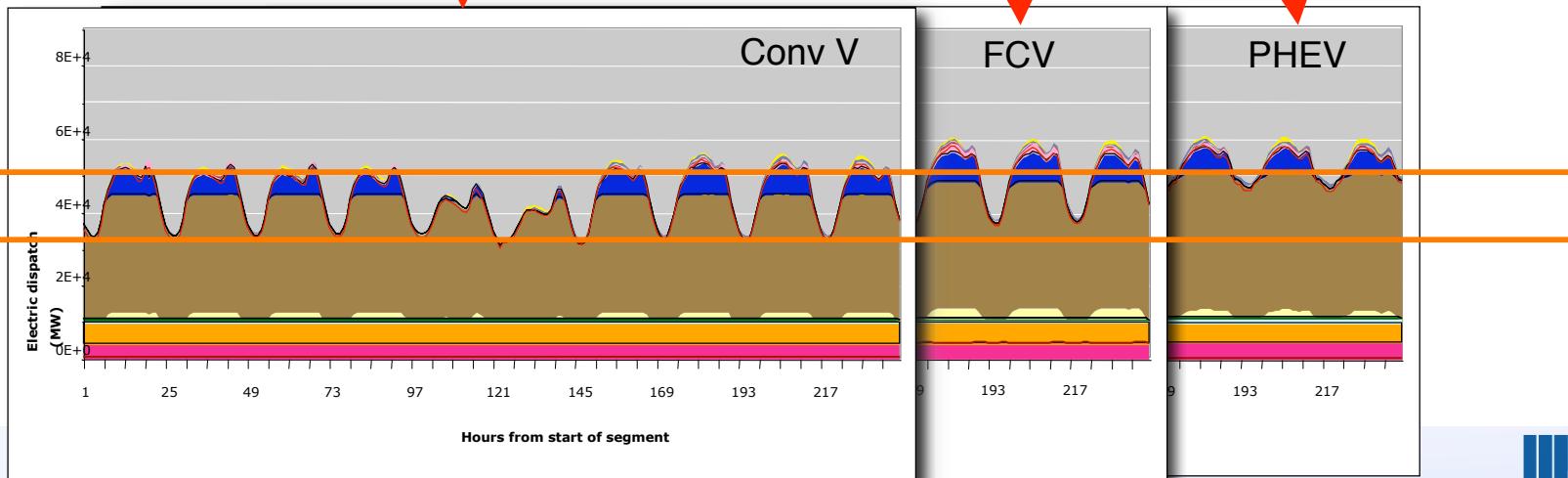
PHEV



Conv V

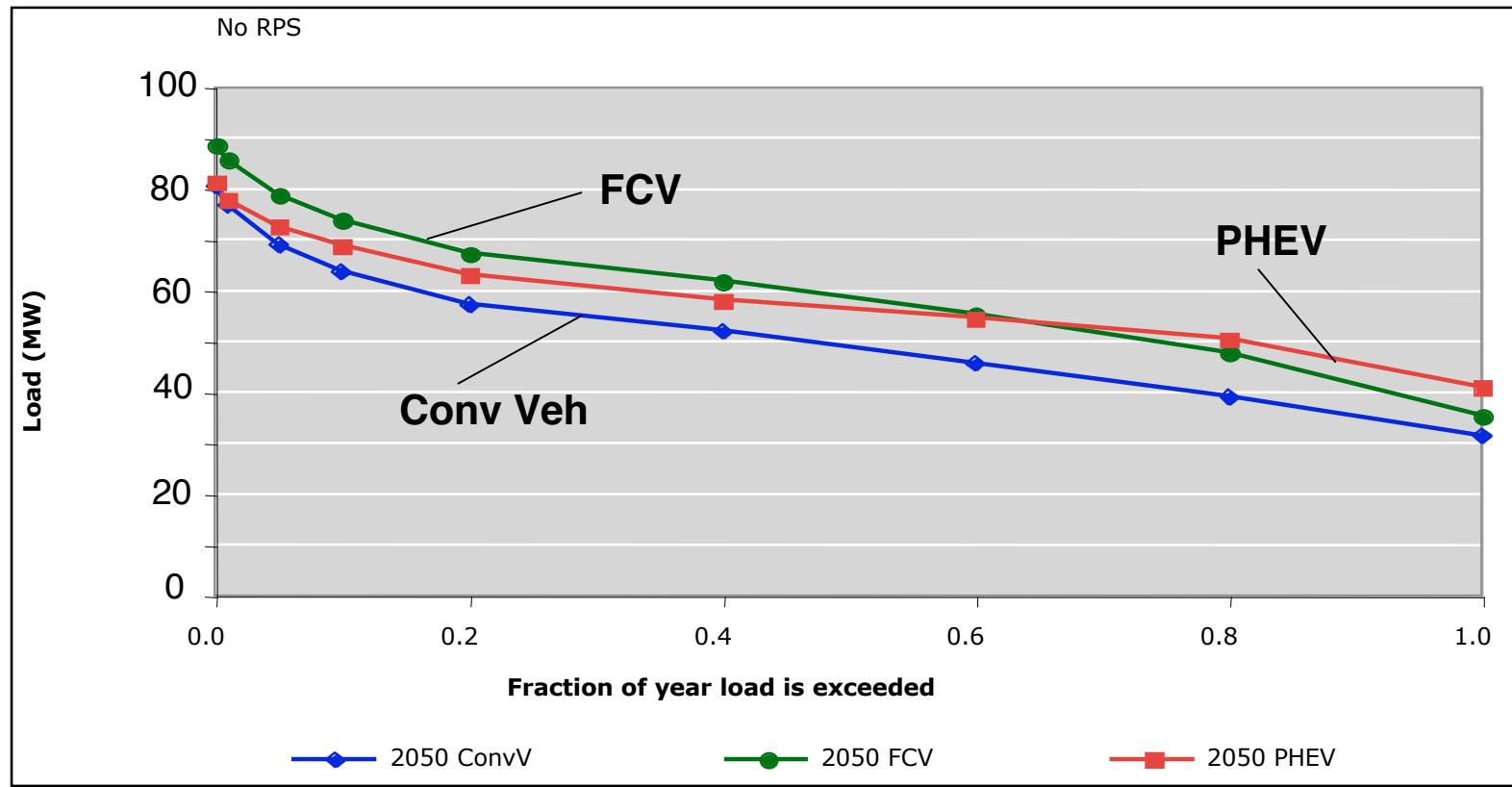
FCV

PHEV

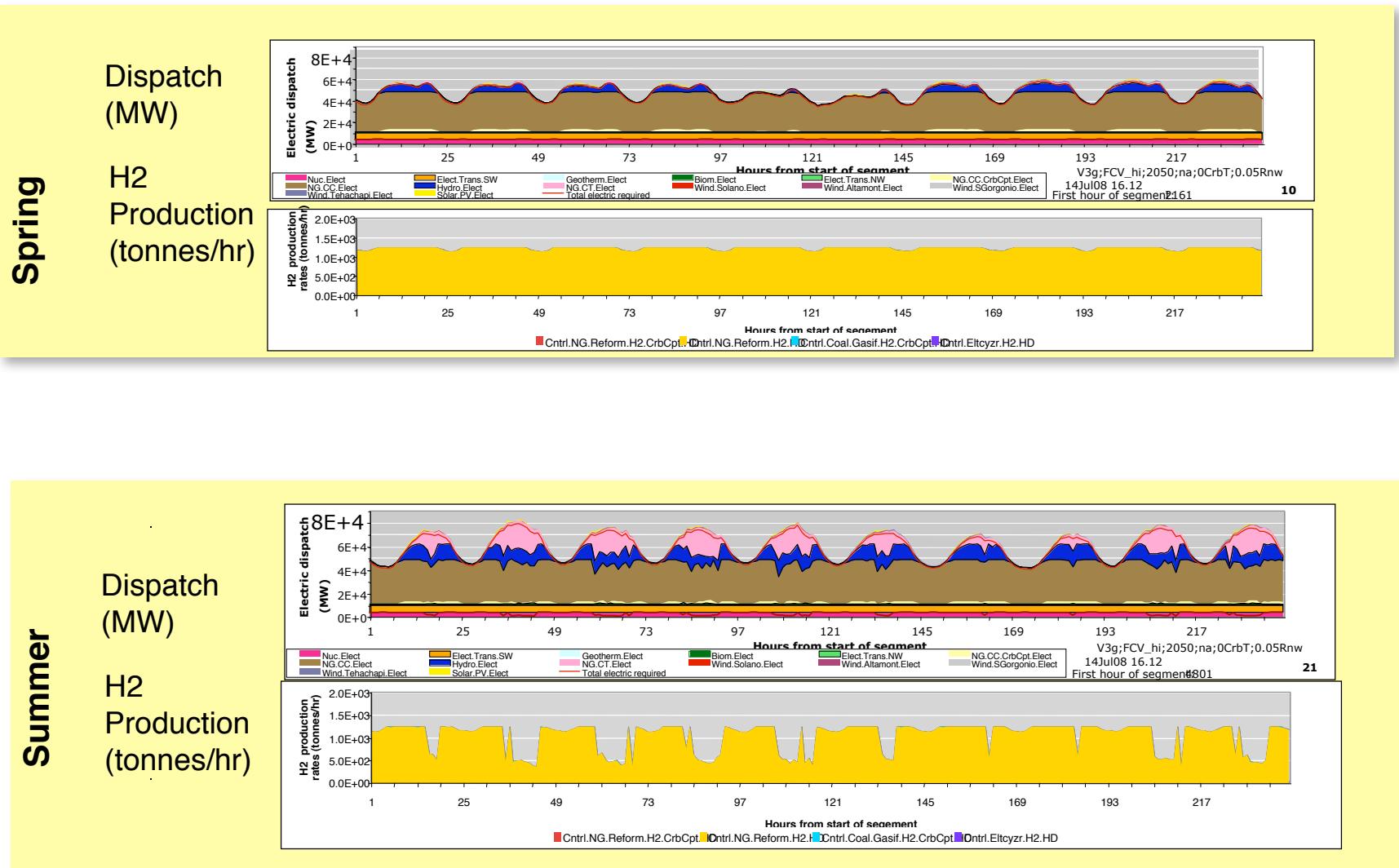


PHEVs and FCVs change the load duration curve

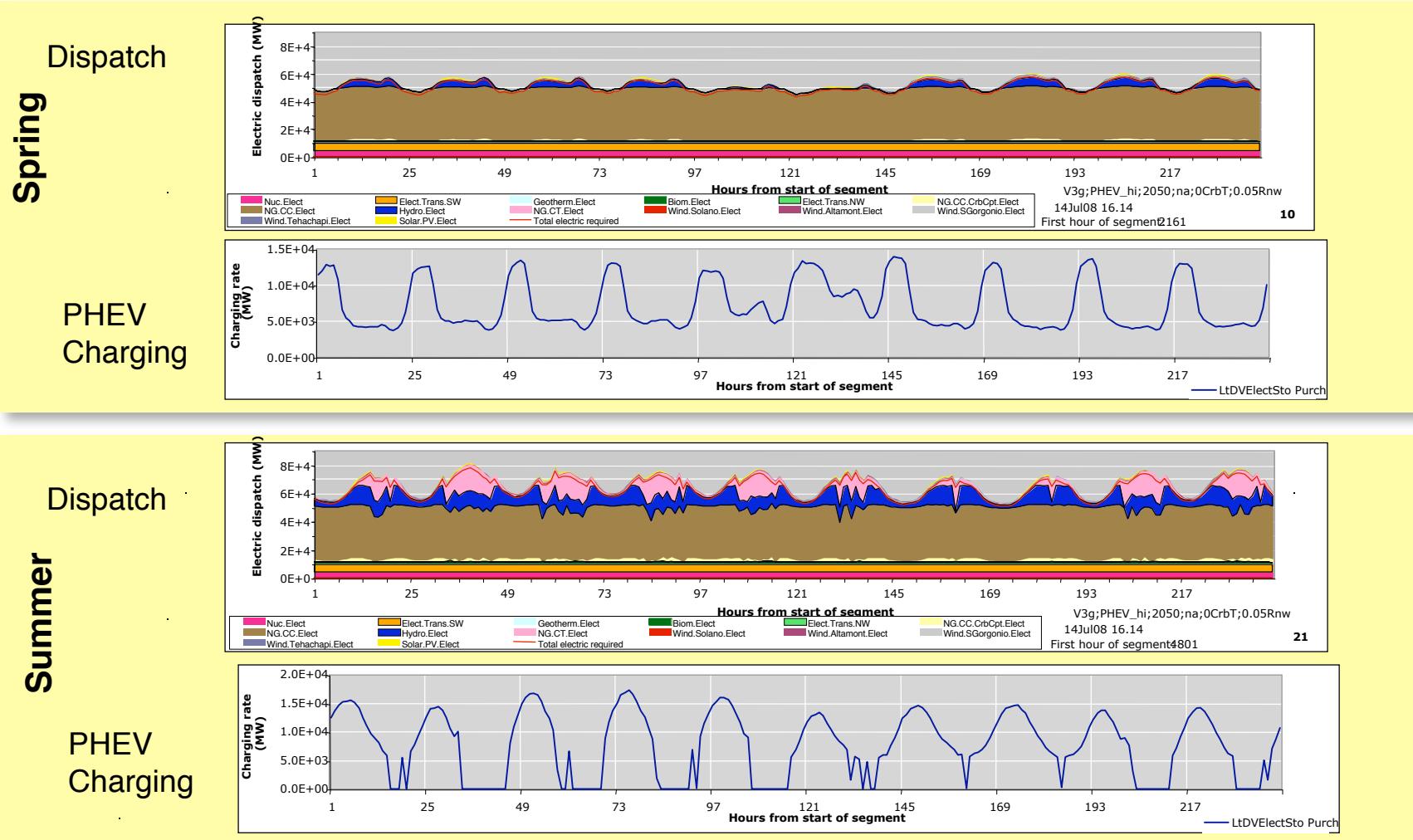
- PHEVs flatten the LDC without increasing the peak



H₂ production interacts with the electric system in the summer



PHEV strongly interacts with the electric system in all seasons



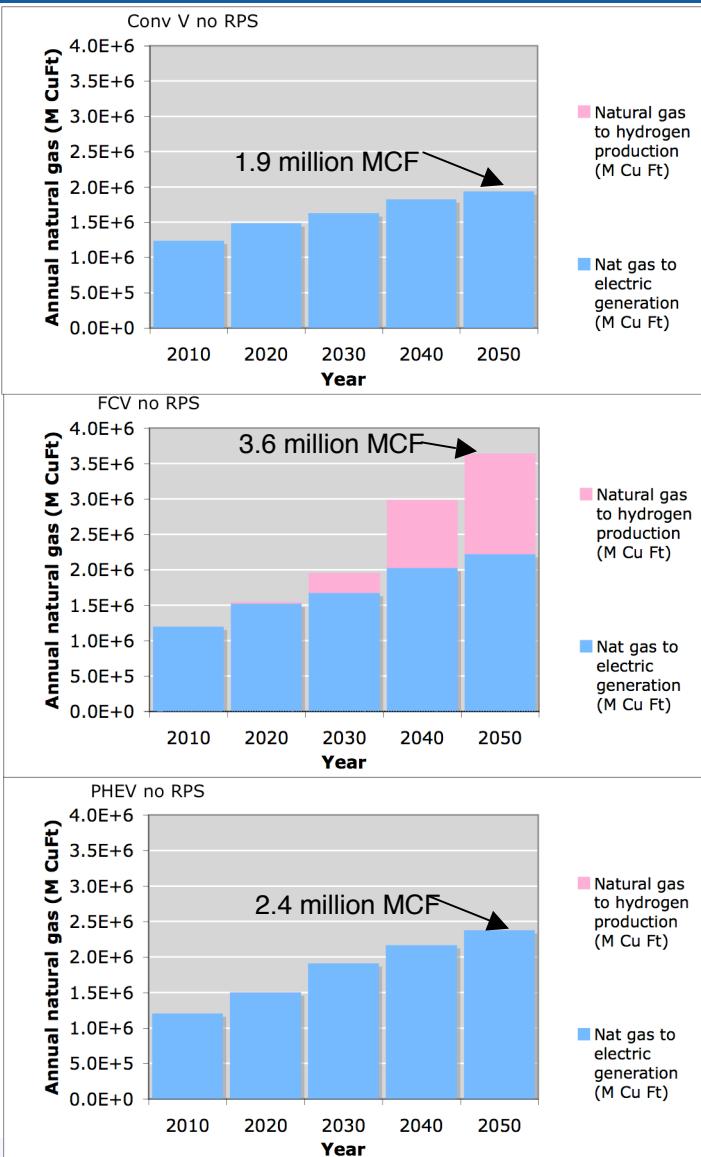
This suggests sophisticated real time pricing and operation

H2 supply pathways

- Urban areas (Sacramento, L. A., San Diego, Bay Area)
 - Central natural gas reformer produces H2
 - Liquid H2 trucks deliver H2 for approximately the first decade
 - After 2030, H2 delivered by pipelines
- Non urban areas (low density of demand)
 - Production by central natural gas reformer
 - Delivered by compressed H2 tanker trucks

Natural gas demand increases substantially with the FCVs

Conv V

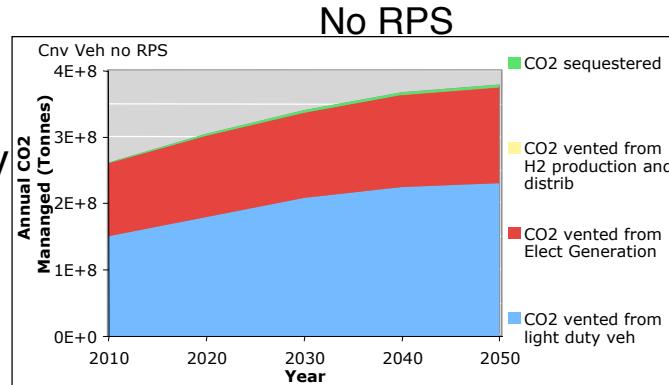


Natural gas to H₂

Natural gas to electric generation

The CO₂ emissions reductions per vehicle are very similar

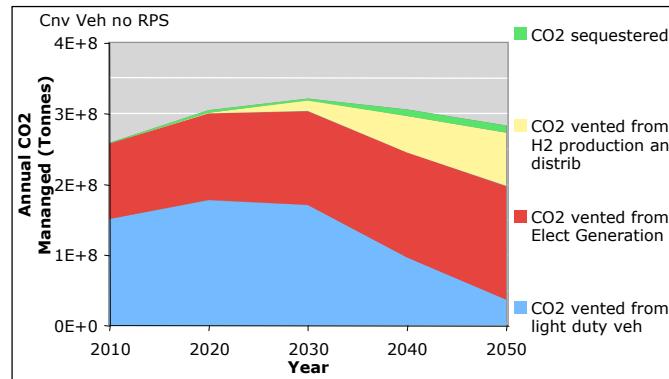
Conv V



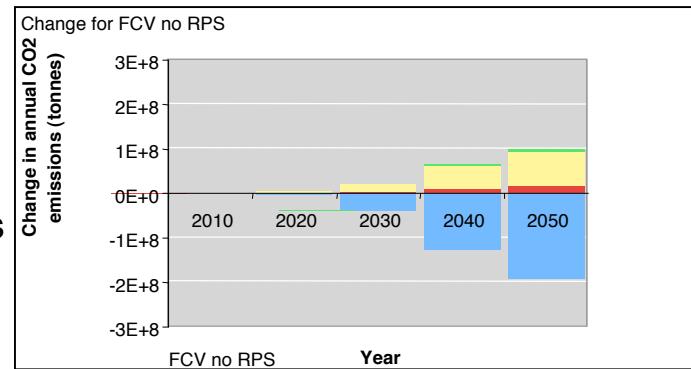
- CO₂ reductions per vehicle
 - FCV: 2.3 tonnes/veh-yr
 - PHEV: 2.2 tonnes/veh-yr

█ sequestered
█ H₂ production and distrib
█ Elect Generation
█ Vented from light duty veh

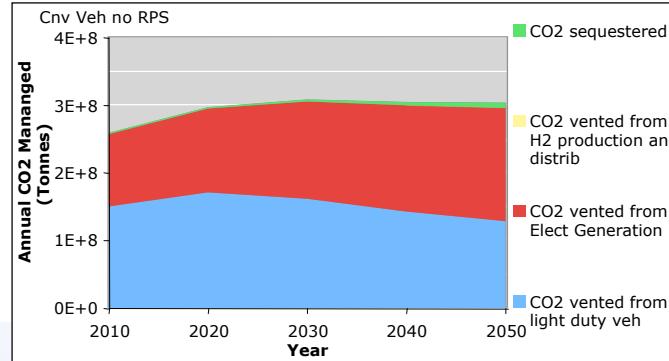
FCV



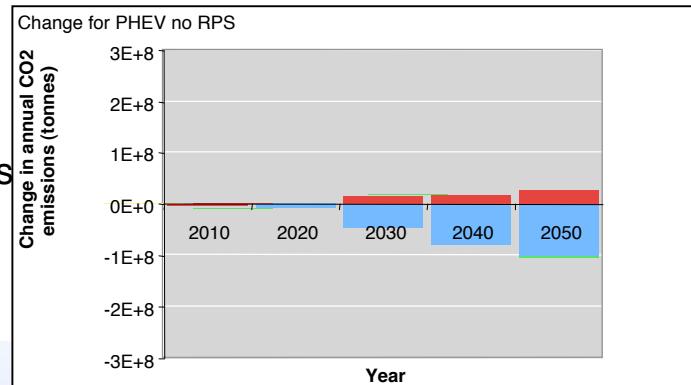
FCV Changes from Conv V



PHEV

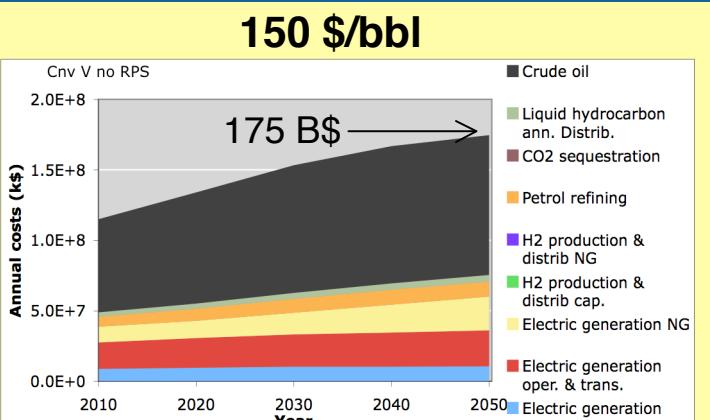
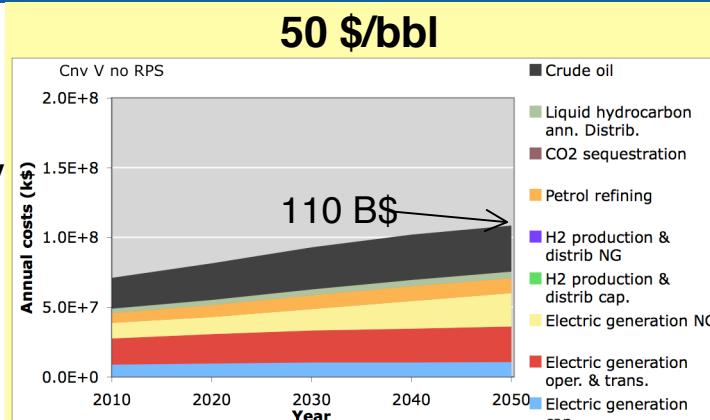


PHEV Changes from Conv V



Costs are similar--at \$50/bbl petroleum At \$150/bbl there are some differences

Conv V



H2 production &
distrib ancillary
oper.

CO2
sequestration

Crude oil

Liquid
hydrocarbon
ann. Distrib

Petrol
refining

H2 production
& distrib NG

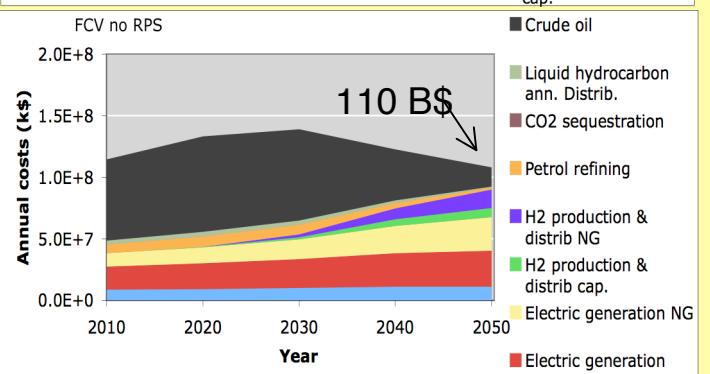
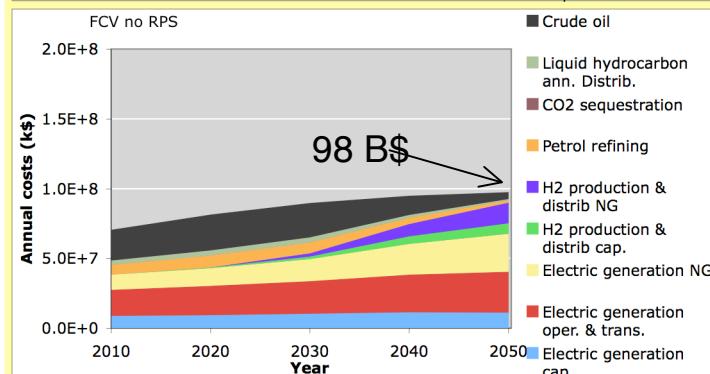
H2 prodn &
distrib cap.

Electric
generation NG

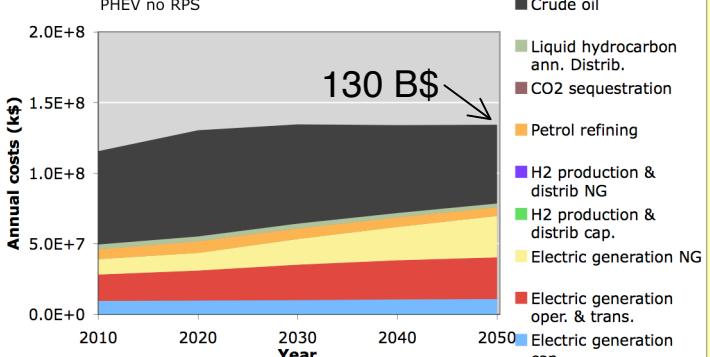
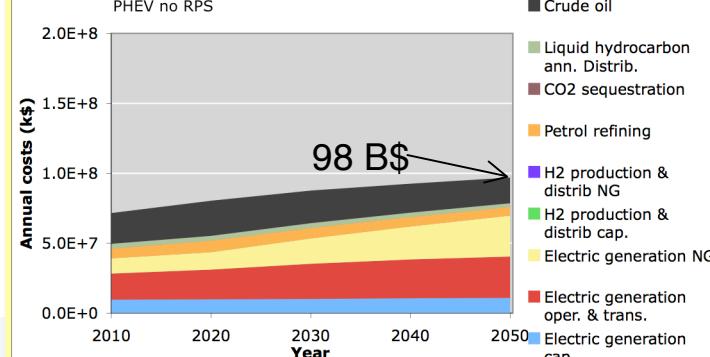
Electric
generation
oper. & trans.

Electric
generation cap.

FCV

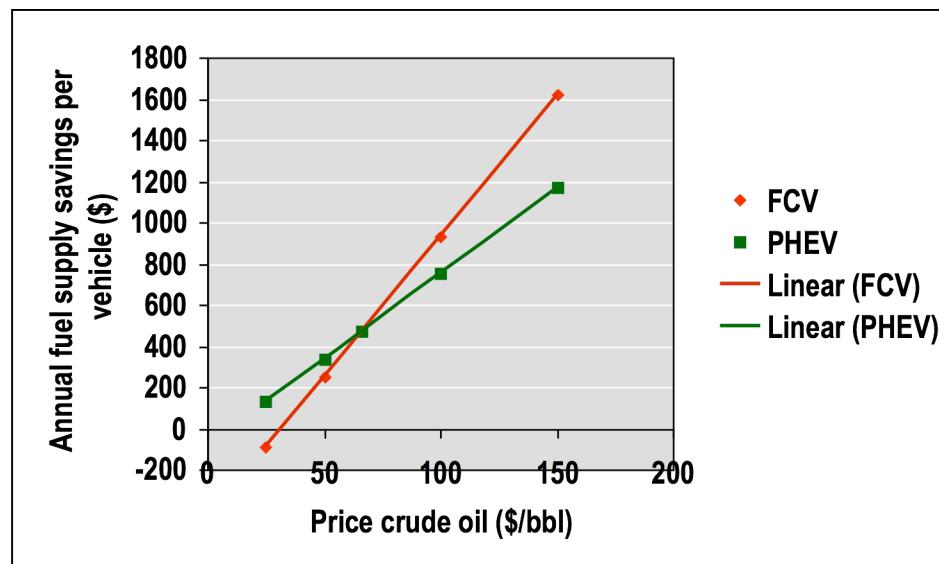


PHEV



Cost savings per vehicle depends on crude oil price

- Analysis only considers costs in the fuel supply sector
 - Advanced vehicles could be more expensive than conventional vehicles
- When crude oil prices are high, there are significant savings



The RPS has a small interaction with advanced vehicles

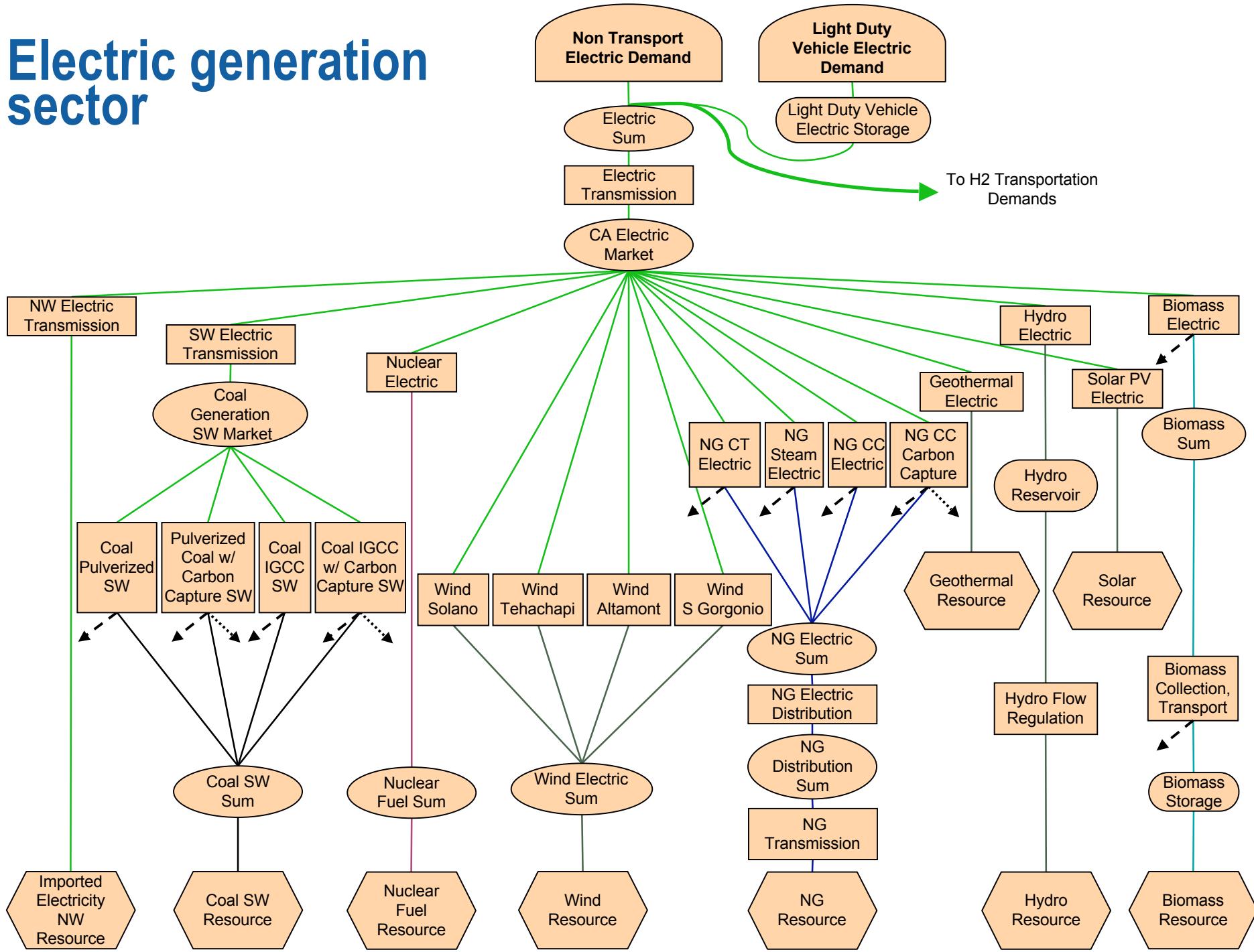
- Roughly cost neutral
 - Capital costs increase, operating costs decrease
- Decrease in Combined Cycle capacity
 - Displaced by geothermal and biomass
 - Displaced by wind, to some extent
- Decrease in 2050 natural gas consumption in electric generation ≈ 0.4 million MCF (out of ≈ 2.0 million MCF)
- Decreases CO₂ emissions from fuel supply by $\approx 14\%$
 - The most efficient generators are displaced
- H₂ production and PEV charging patterns are modified slightly by wind and solar production patterns

Conclusions

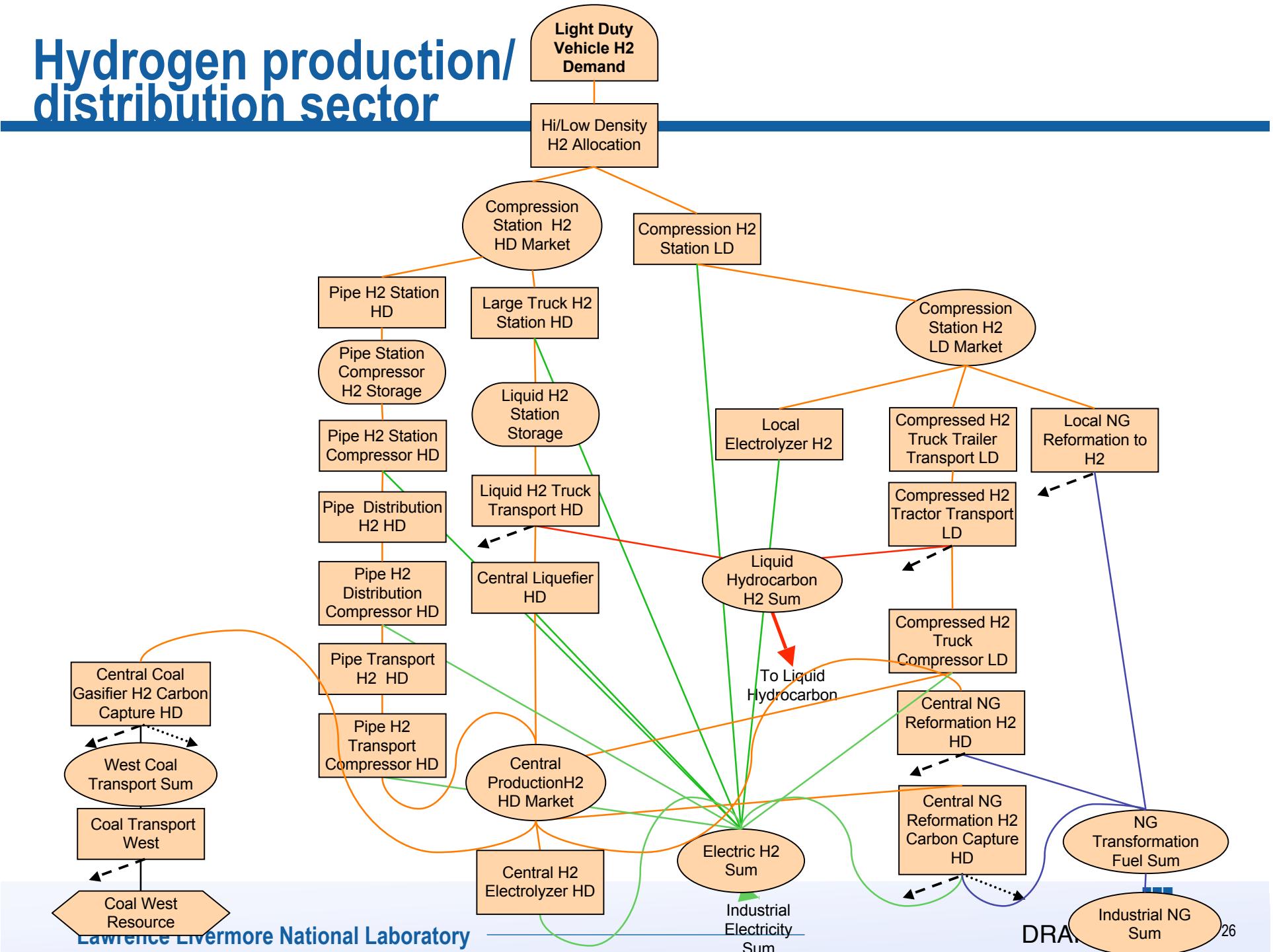
- **Electric system impacts**
 - PHEVs smooth electric generation
 - increase combined cycle capacity and generation
 - greater efficiency
- **Costs and resources**
 - Both FCVs and PHEVs reduce costs by reducing crude oil purchases
 - FCVs almost double the natural gas demand
- **Emissions**
 - FCVs and PHEVs are very similar in their emissions, per vehicle
- **System management**
 - Managing the charging patterns of PHEVs will require a smart grid and attention from the consumers

Extras

Electric generation sector

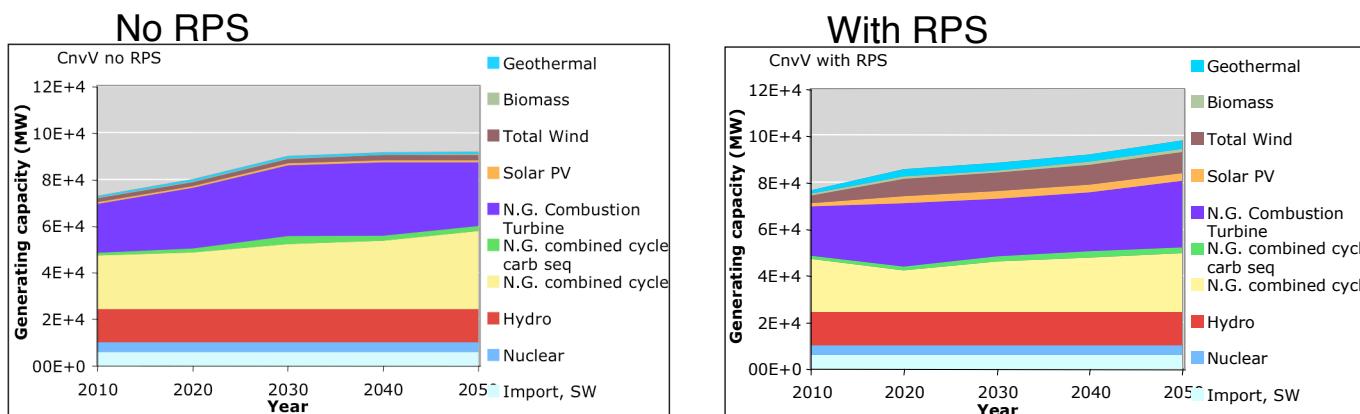


Hydrogen production/distribution sector

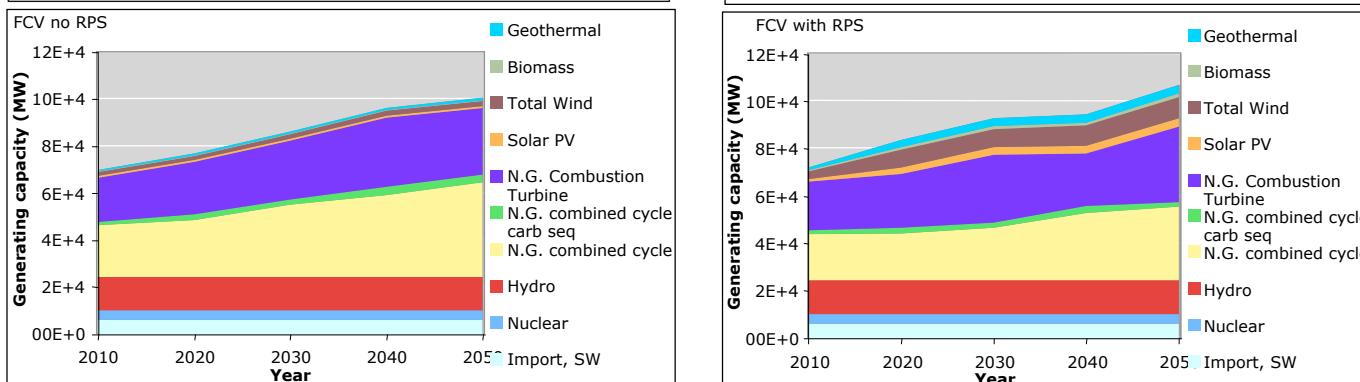


FCV and the RPS increase electric system capacities

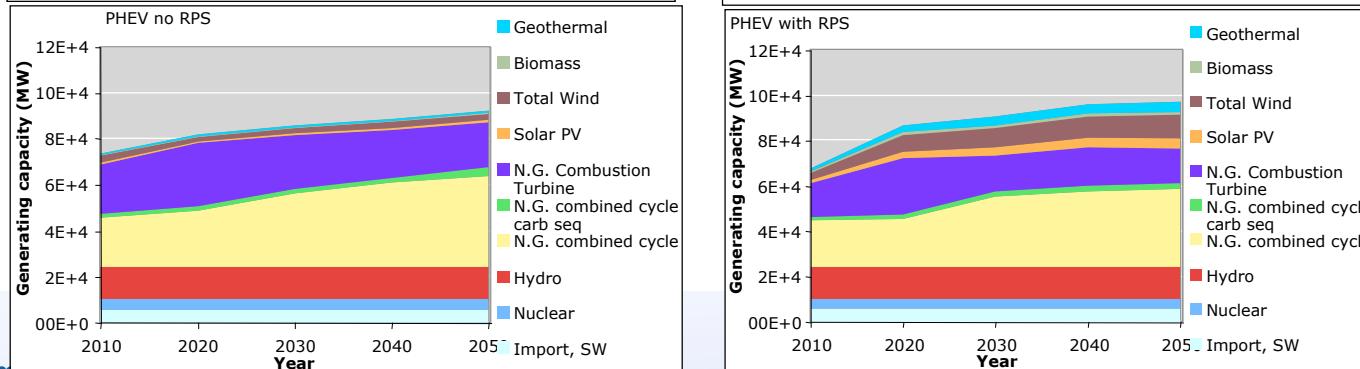
Conventional vehicles



Fuel Cell vehicles

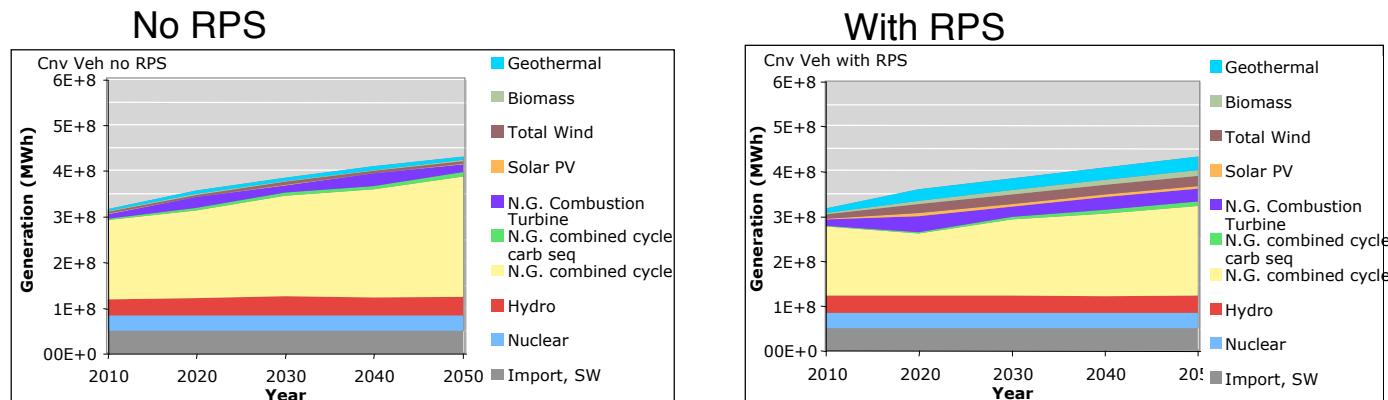


Plug-in Hybrid vehicles

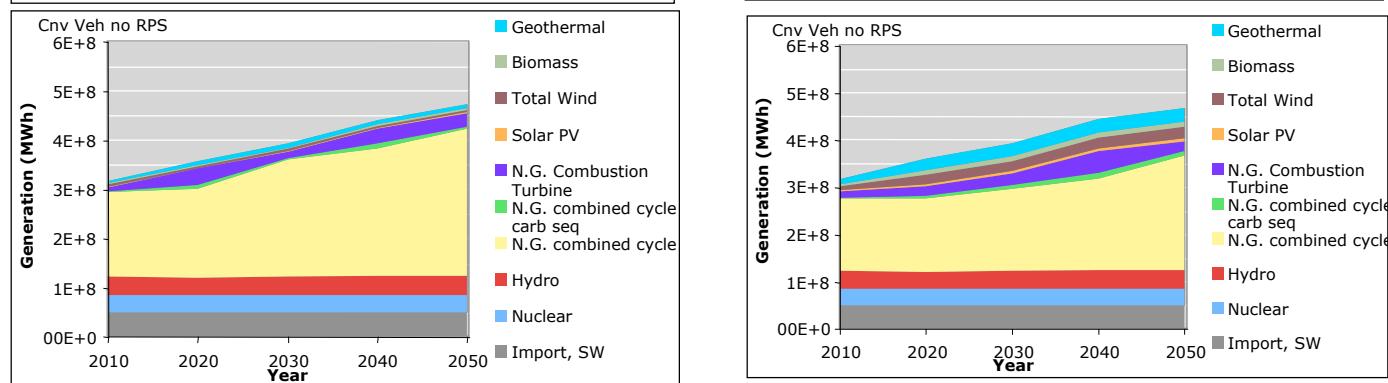


Electric system generation over time

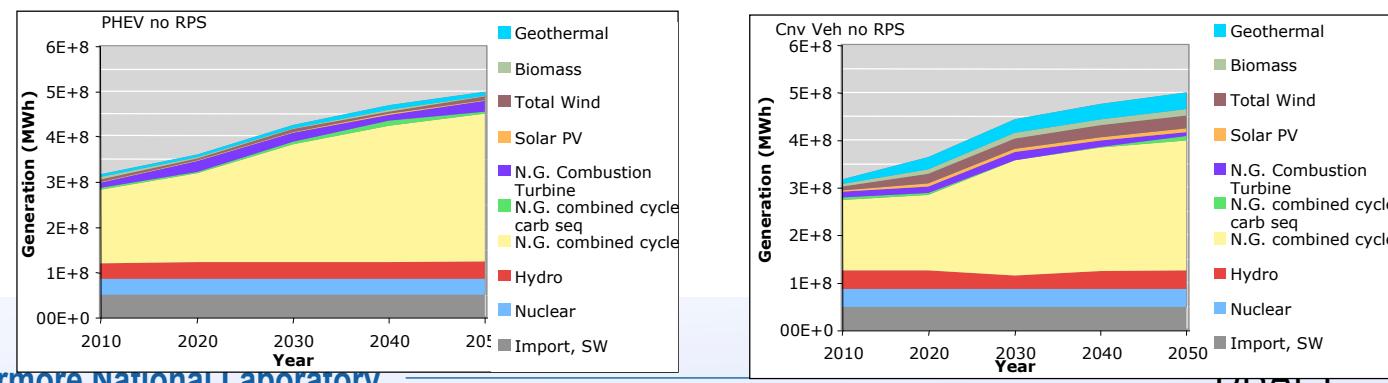
Conventional vehicles



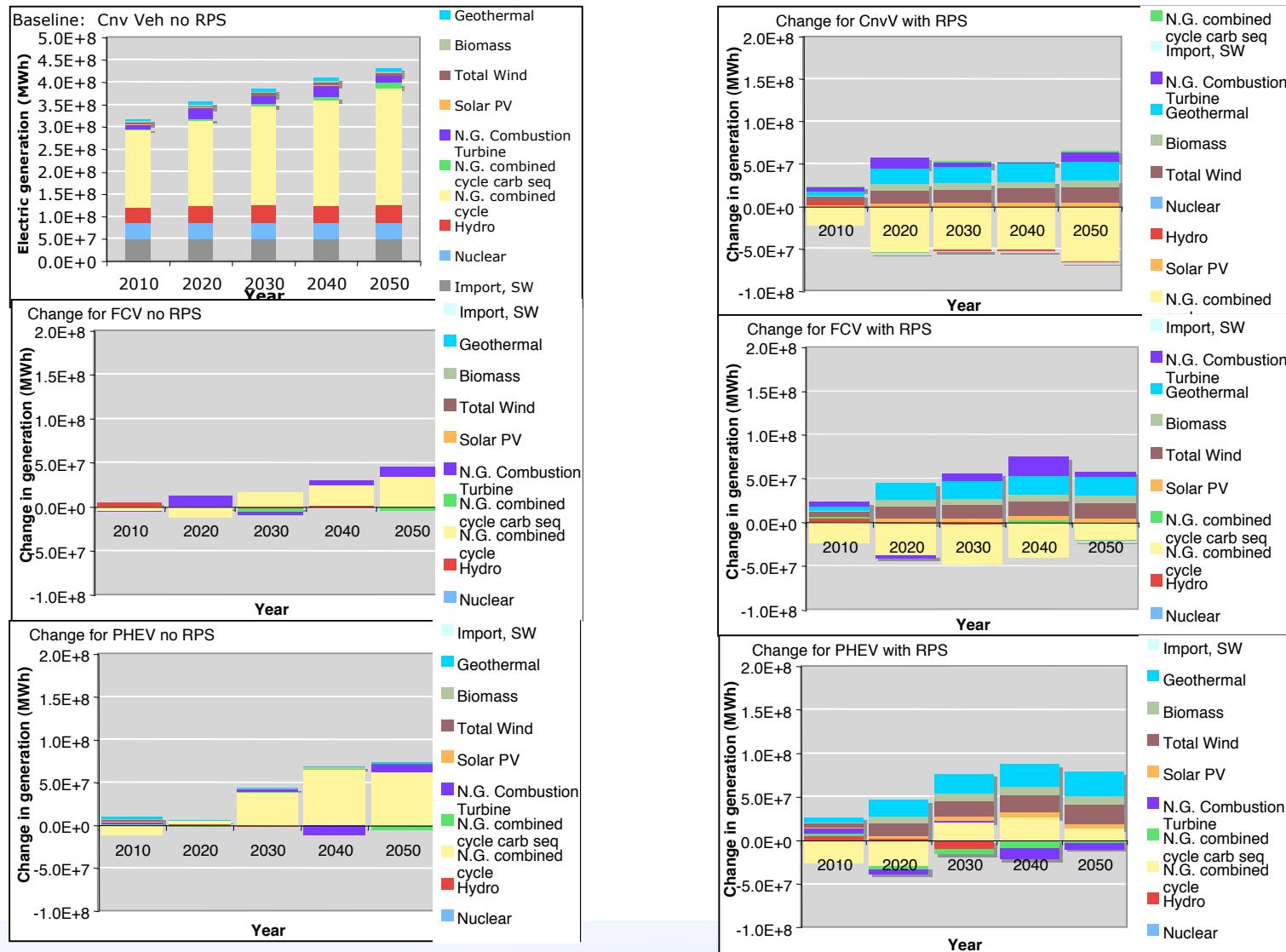
Fuel Cell vehicles



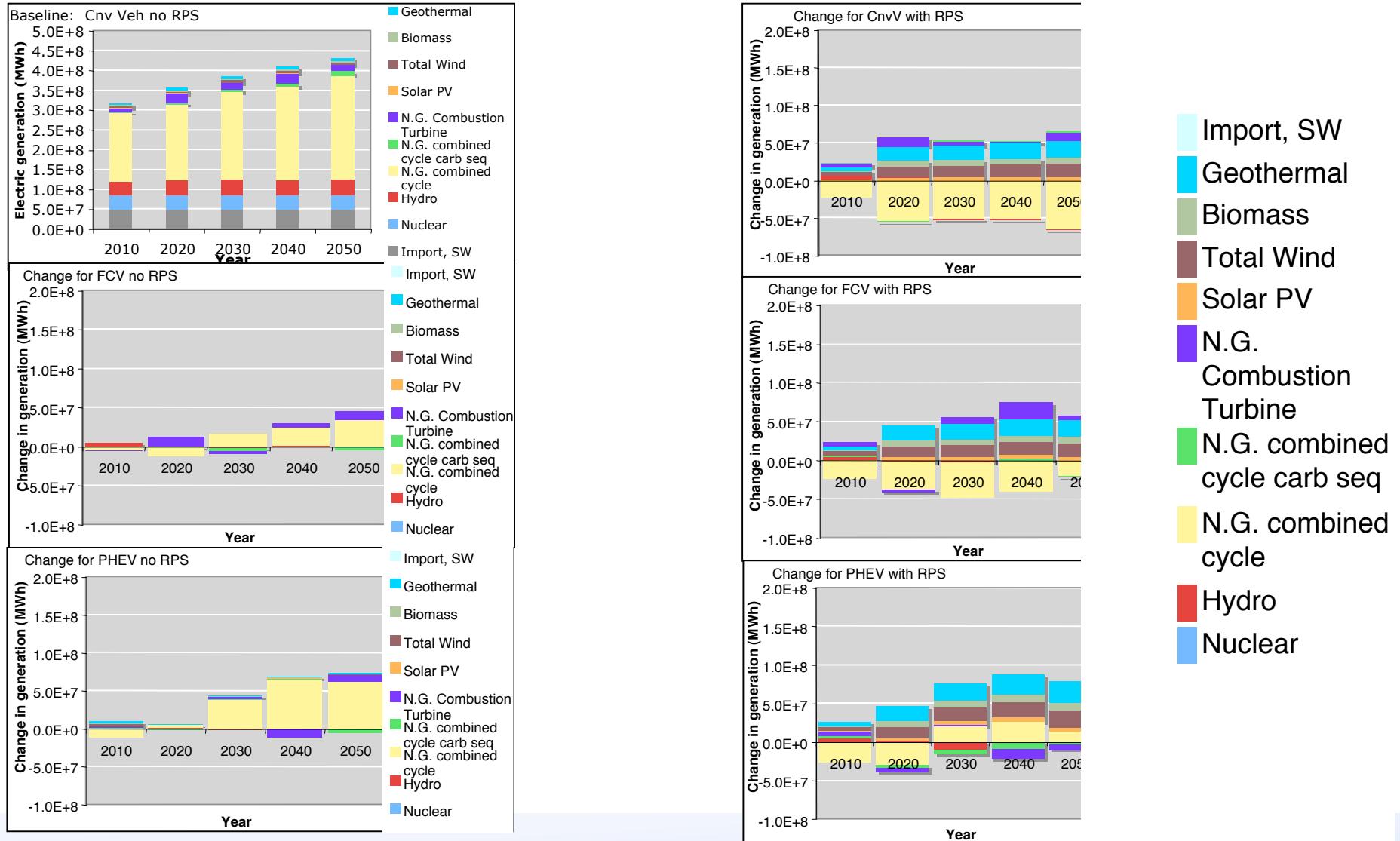
Plug-in Hybrid vehicles



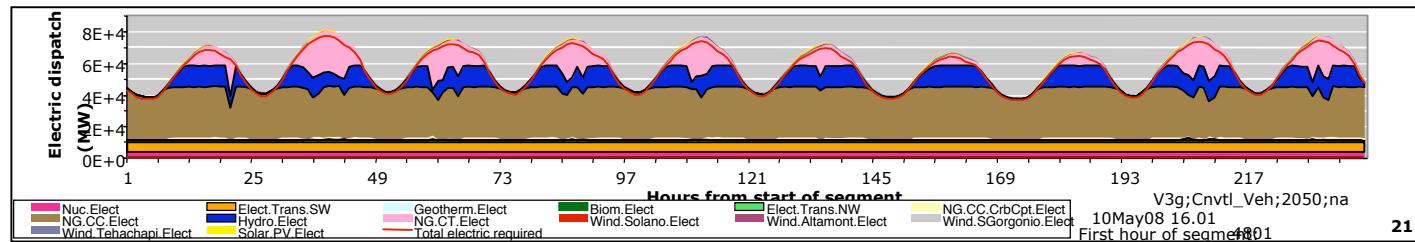
Changes in electric generation



Changes in electric generation



Summer dispatch, conventional vehicles, 2050



Operation of electric system with conventional vehicles

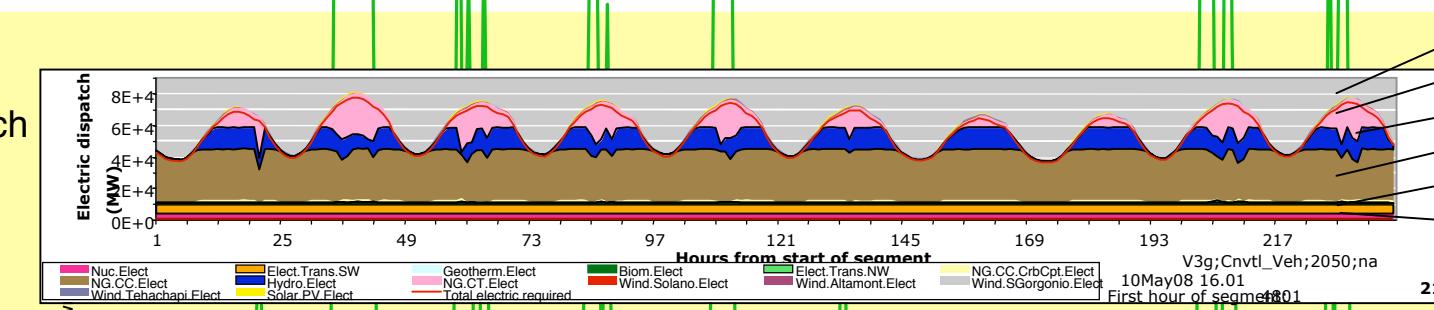
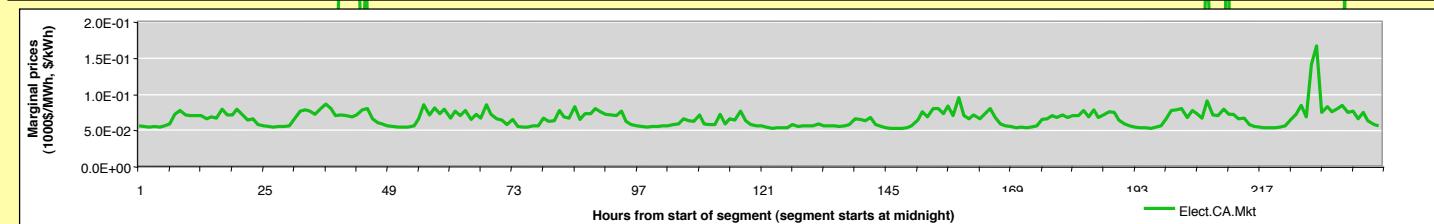
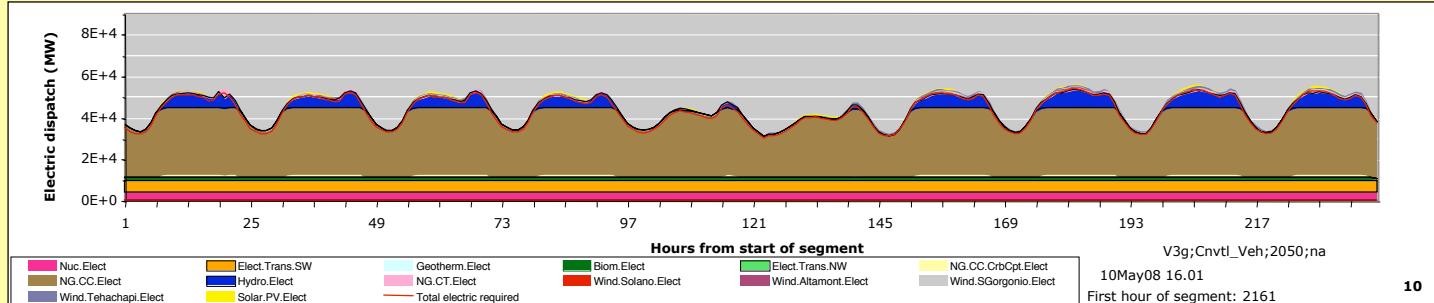
Dispatch

Spring

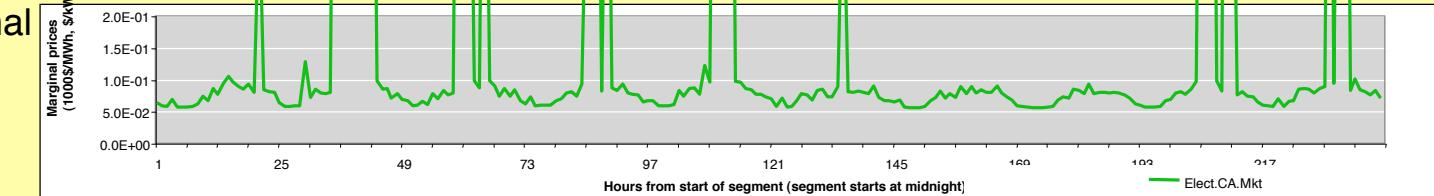
Marginal prices

Summer Dispatch

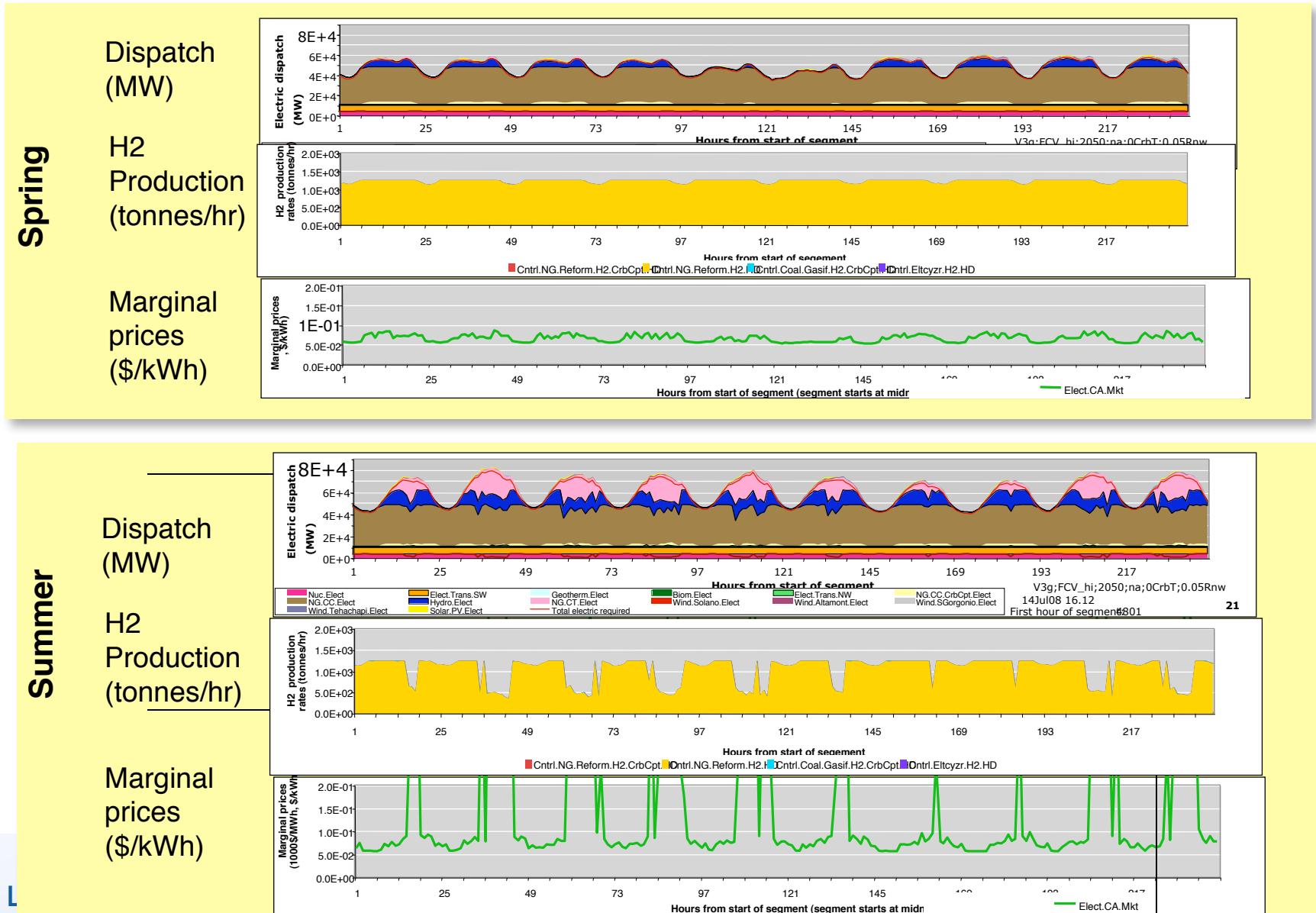
Marginal prices



- Wind and solar Peaker
- Hydro
- Combined cycle
- SW Imports
- Nuclear

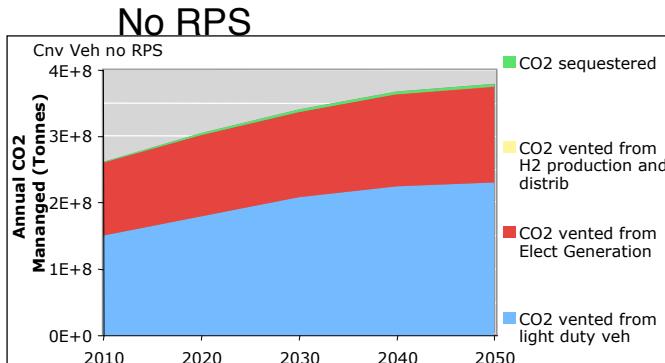


H2 interacts with the electric system in the summer

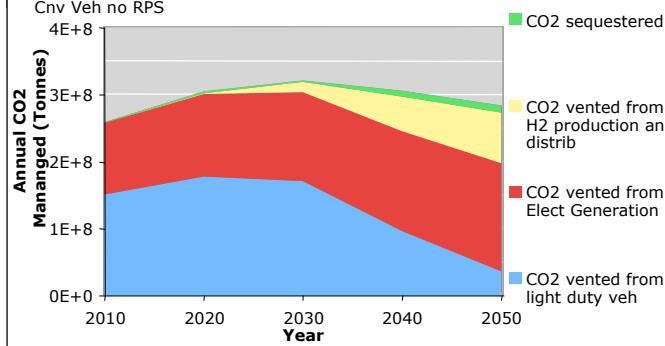


Emissions reductions are similar for the vehicle cases

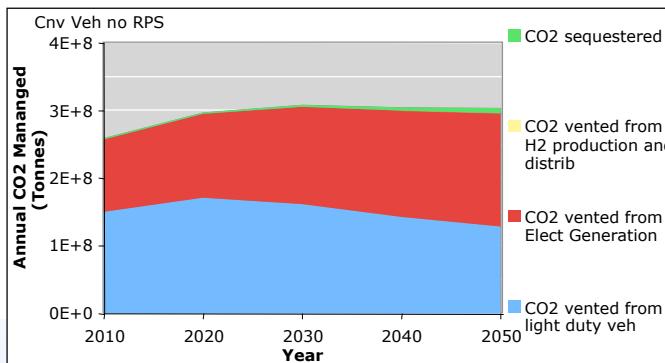
Conventional vehicles



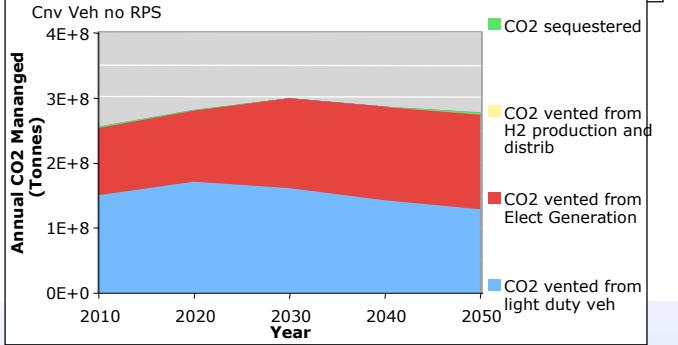
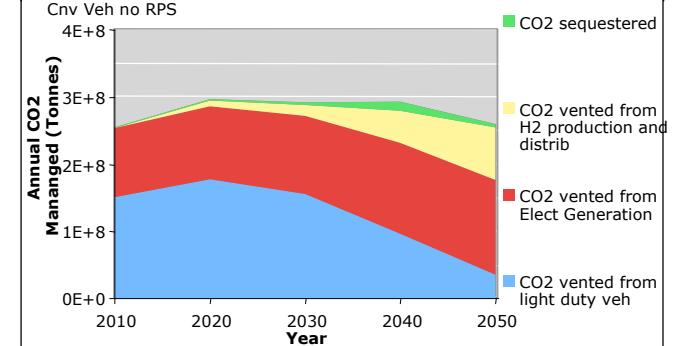
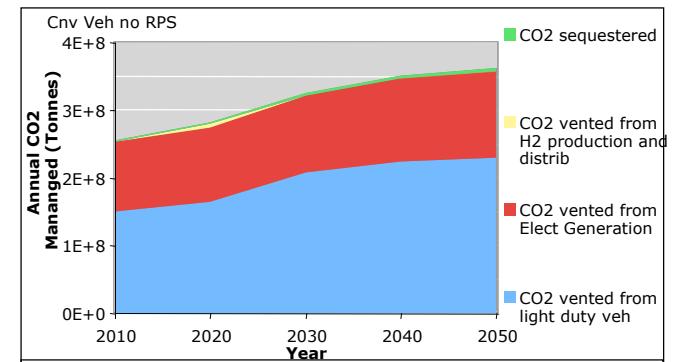
Fuel Cell vehicles



Plug-in Hybrid vehicles



With RPS



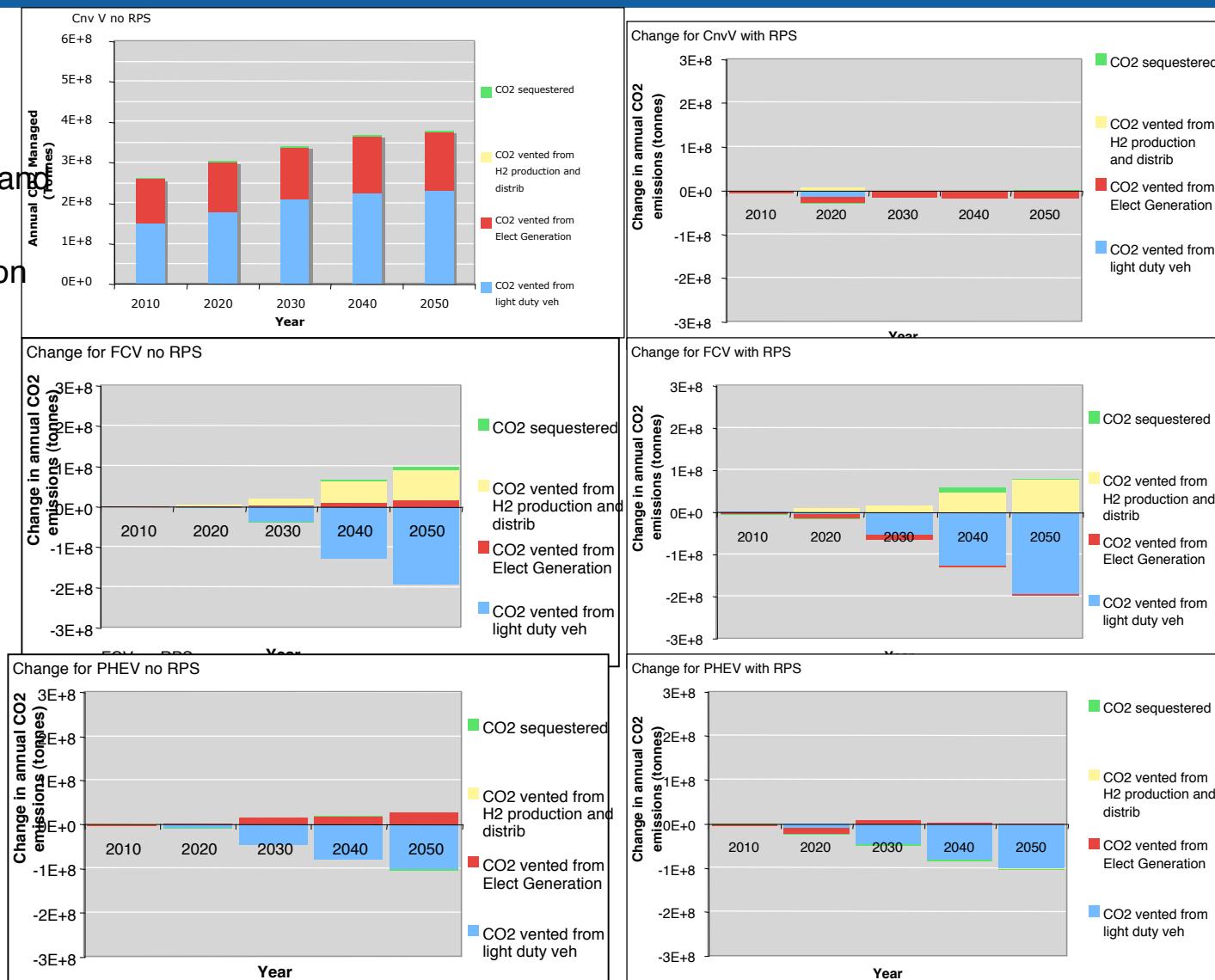
Changes in CO₂ emissions, from conventional vehicles

█ sequestered

█ H₂ production and distrib

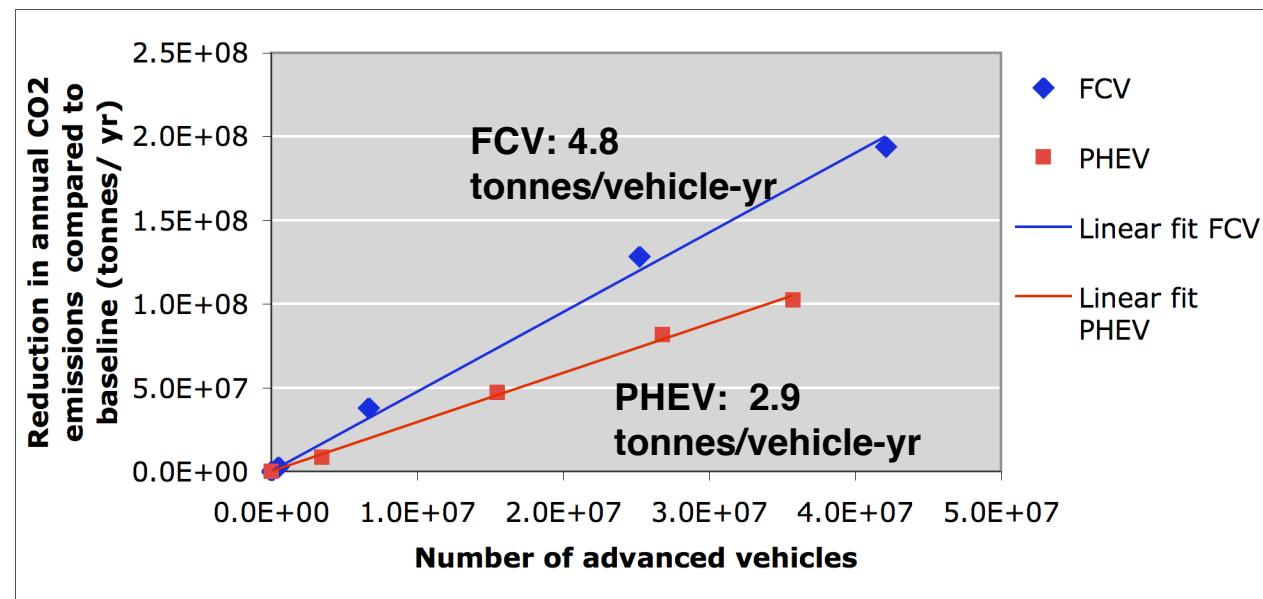
█ Elect Generation

█ light duty veh



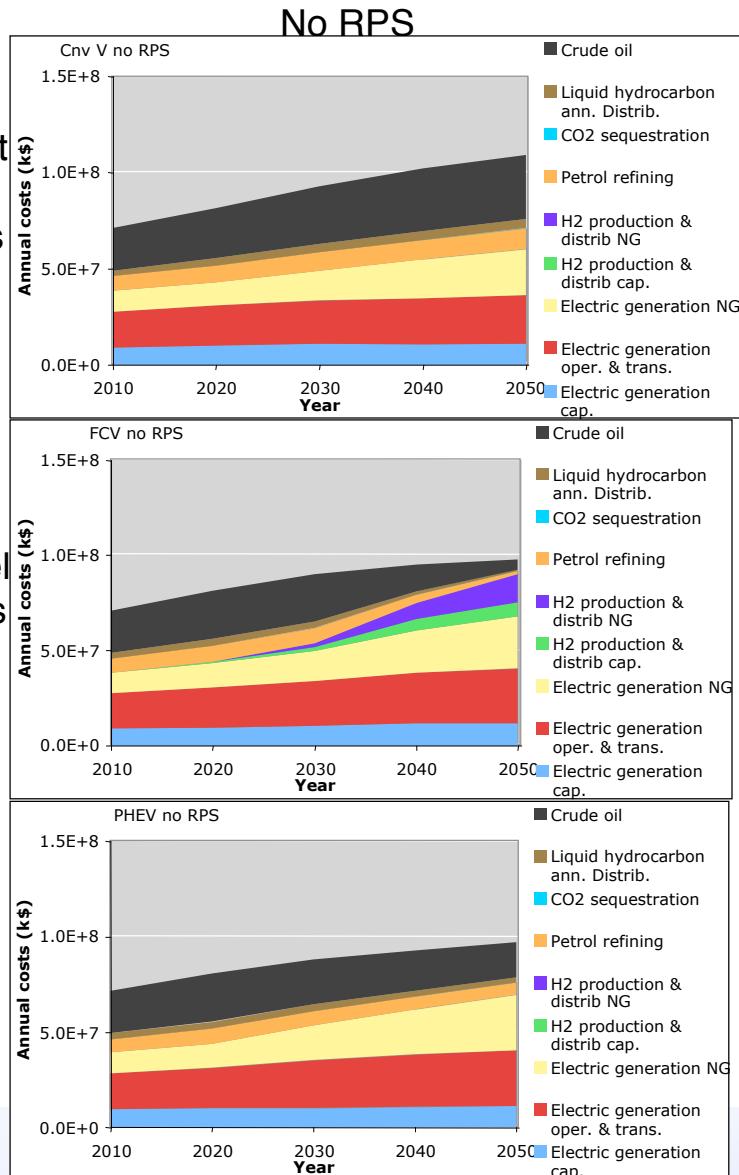
Annual reduction in emissions, per vehicle

- FCVs reduce annual emissions by about 4.76 tonnes/vehicle and the PHEVs reduce emissions by about 2.94 tonnes/vehicle.

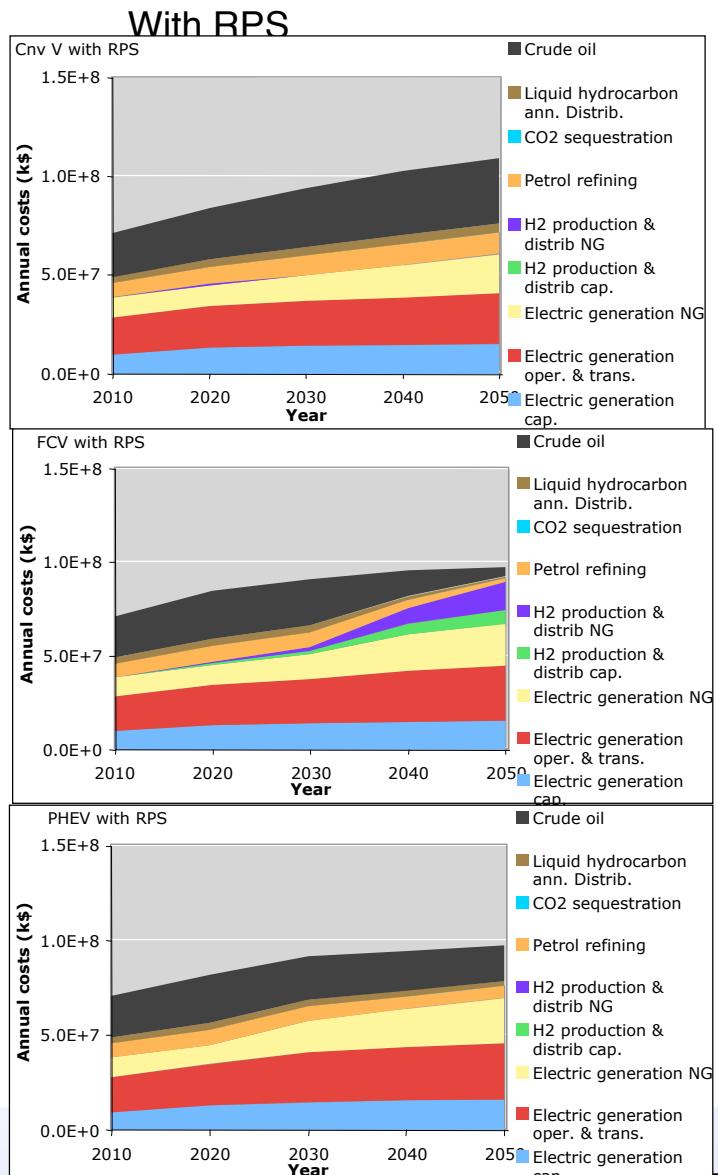


Costs are similar--at \$50/bbl petroleum

Conventional vehicles



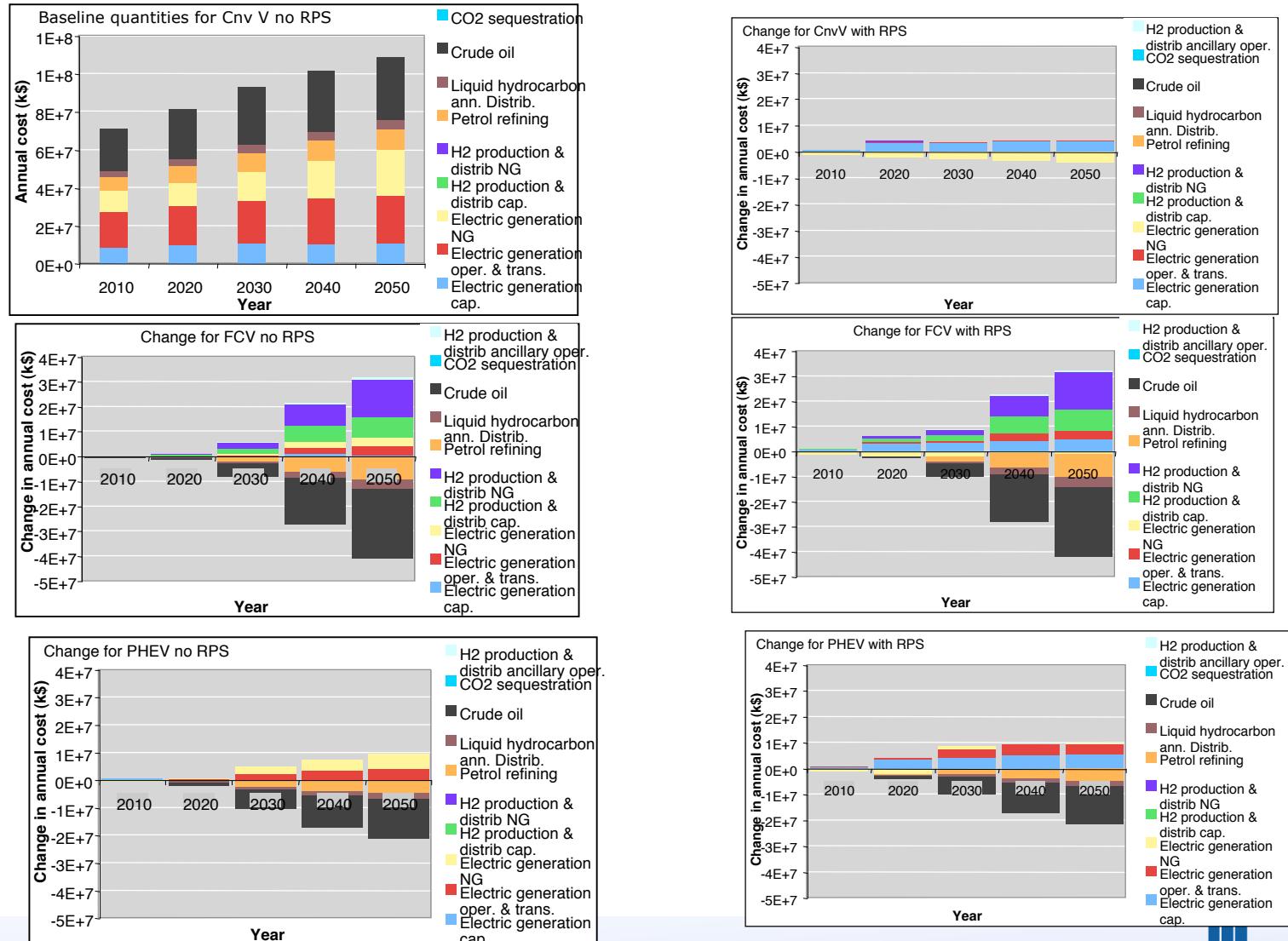
Fuel Cell vehicles



Plug-in Hybrid vehicles

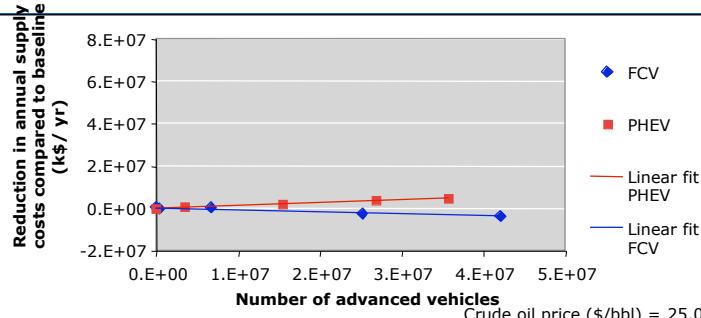
- H2 production & distrib ancillary oper.
- CO2 sequestration
- Crude oil
- Liquid hydrocarbon ann. Distrib.
- Petrol refining
- H2 production & distrib NG
- H2 production & distrib cap.
- Electric generation NG
- Electric generation oper. & trans.
- Electric generation cap.

Changes in cost components



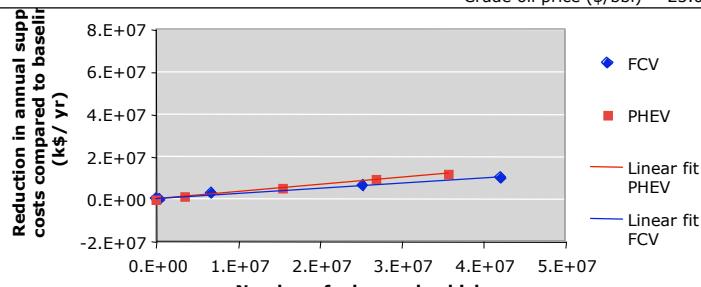
Savings per vehicle depends on crude oil price

25 \$/bbl



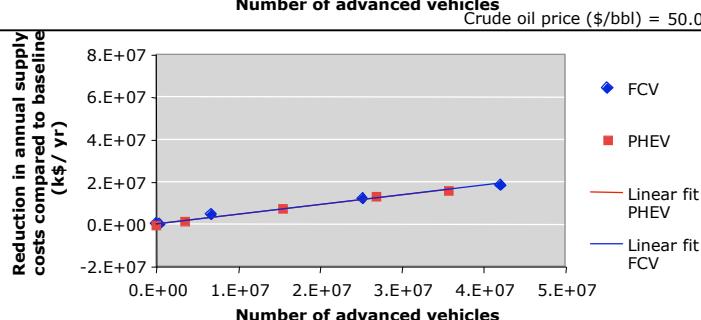
50 \$/bbl

Used in study



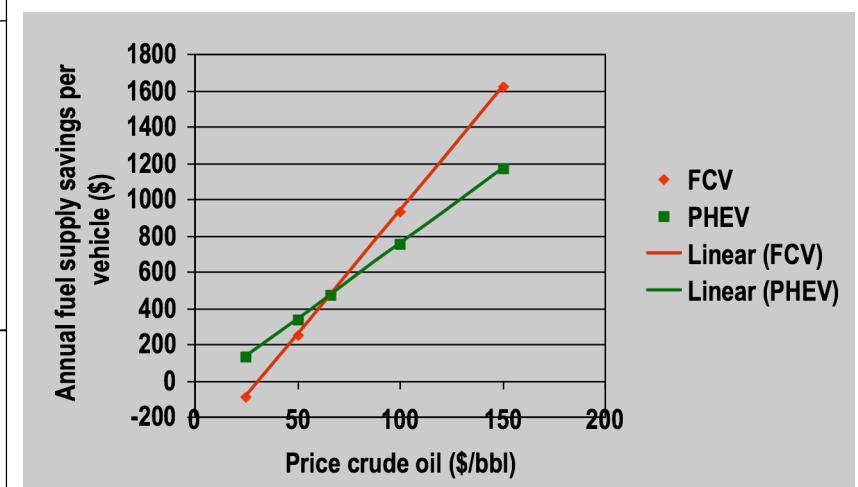
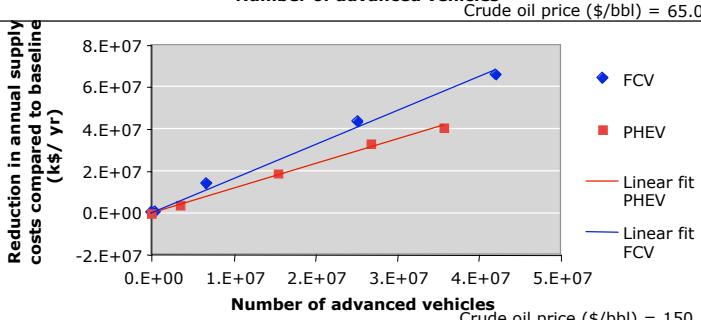
66 \$/bbl

Equal savings



150 \$/bbl

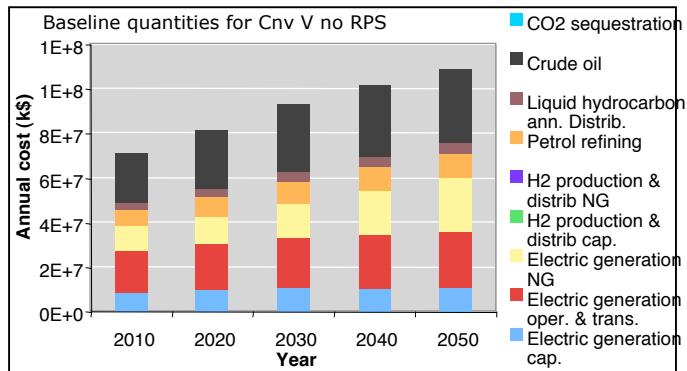
Ridiculous



Changes in cost components

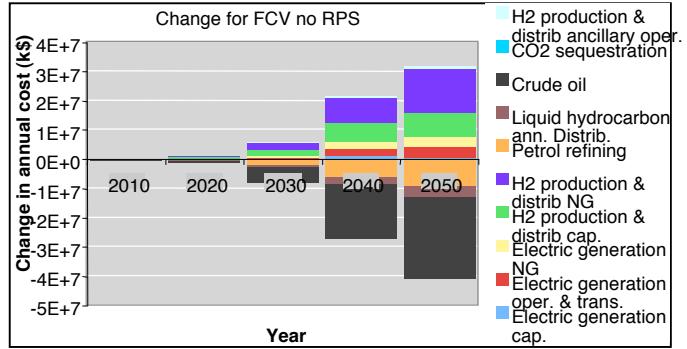
Conv V

Baseline costs



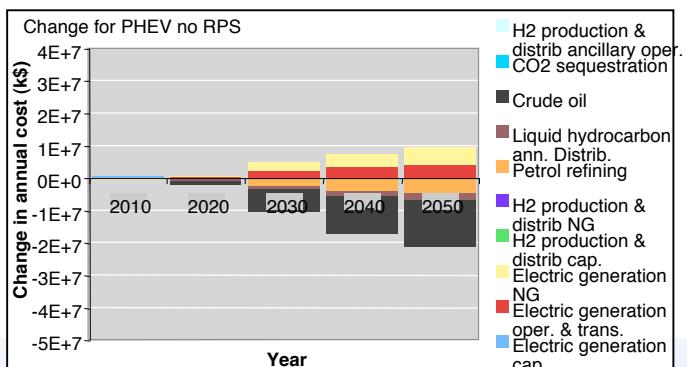
FCV

Difference from conventional vehicles



PHEV

Difference from conventional vehicles



- H2 production & distrib ancillary oper.
- CO2 sequestration
- Crude oil
- Liquid hydrocarbon ann. Distrib.
- Petrol refining
- H2 production & distrib NG
- H2 production & distrib cap.
- Electric generation NG
- Electric generation oper. & trans.
- Electric generation cap.